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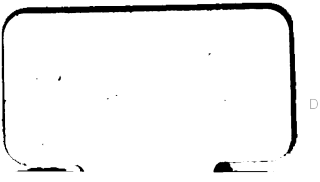

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MODERN METEOROLOGY

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MODERN METEOROLOGY

A Series of Six Lectures

DELIVERED UNDER THE AUSPICES OF THE METEOROLOGICAL SOCIETY IN 1878

ILLUSTRATED

LONDON
EDWARD STANFORD, 55 CHARING CROSS, S.W.
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PREFACE.

THE Science of Meteorology, as it is studied at the present day, may well receive the designation of "modern." Its renovation dates from the proposal to employ telegraphy in the transmission of meteorological observations, which proposal was realised hardly more than a quarter of a century ago.

As soon as observations collected by telegraphy were laid down on charts, an entirely new light was thrown upon the complex phenomena included under the simple term "weather"; and by the publication of the charts so prepared, the public were admitted to the study of the processes of weather production by the mutual action of cyclones and anticyclones. The diffusion of this knowledge, however, is slow; and it appeared to the Council of the Meteorological Society that a set of Lectures

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A. A. Munro June 2. 1879.

explanatory of modern views, and showing how the stock of knowledge of an older date may be thereby illustrated, would, in the present condition of the science, be well timed.

Arrangements were made by the Council of the Meteorological Society to deliver in the autumn of 1878 the course of Lectures which are reproduced in the following pages.

The Council of the Institution of Civil Engineers most graciously lent the use of their theatre for the six evenings, and to that body the thanks of the Meteorological Society are most gratefully tendered.

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SYLLABUS.

LECTURE I.

THE PHYSICAL PROPERTIES OF THE ATMOSPHERE.

By ROBERT JAMES MANN, M.D., F.R.C.S., F.R.A.S., F.R.G.S., V.P.M.S.

DEFINITION and object of meteorological science—Purpose and plan of this course of lectures—Meteorology based on the physical properties of the atmosphere—Invisibility of air—Its weight—Minuteness of particles—The gaseous state—Kinetic theory—Inherent movements of atoms—Compressibility of air—Expansion by heat—Contraction by cold—Influence of gravity upon its condition—The law of Boyle and Mariotte—Pressure increases in same ratio as volume—Regnault's law—The limits of the atmosphere—Highest ascents of balloon—M. Liais' views—Specific gravity of air—Specific gravities of mercury, water, and glycerine—Torricelli's invention of mercurial barometer—Pascal's proof of Torricelli's views—Glycerine barometer of Mr. Jordan—Pressure of air in all directions—The same on all areas of equal size—Relation of area of cistern to area of column of barometer—Pressure in all directions the cause of wind-movement—Atmospheric pressure

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retical depth of a homogeneous atmosphere—Pressure on a square foot and square mile—Weight of the entire atmosphere —Constituent elements of air—Oxygen and nitrogen—Law of gaseous diffusion—Vaporisation of water—Relations of aqueous vapour and atmosphere—Saturation varies with temperature —Capacity of air for aqueous vapour doubled with each increase of 27° of temperature—Elastic force of atmospheric vapour—Determining cause of clouds and rain—Influence of aqueous vapour of the air on the barometer—Influence of evaporation on temperature—Evaporation causes cold—Condensation sets free heat—Warmth promoted by rain—Cause of low temperature of high regions of the air—Limiting temperatures of atmosphere—Diathermancy of dry air—Aqueous vapour acts as a heat screen—Scorching sunshine of mountain tops—Softened character of tropical heat—Atmospheric carbonic acid and ammonia—Fixity of constitution of atmosphere —Ozone, a modified condition of oxygen—Transparency of air —Importance of diathermancy and transparency to terrestrial life—The blue sky dependent on atmosphere—Cause of sunset colours.

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AIR TEMPERATURE, ITS DISTRIBUTION AND RANGE.

By JOHN KNOX LAUGHTON, M.A., F.R.A.S., F.R.G.S., F.M.S., Mathematical Instructor and Lecturer in Meteorology at the Royal Naval College, Greenwich.

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syphon a standard for travellers—Relative merits of these as regards accuracy and permanence of errors—The Kew-pattern Barograph—What the barometer has told us—Popular use of, as a weather glass—The aneroid a substitute for the barometer—Use of, in measuring heights and contouring.

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CLOUDS AND WEATHER SIGNS.

By the Rev. W. CLEMENT LEY, M.A., F.M.S.

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RAIN, SNOW, HAIL, AND ATMOSPHERIC ELECTRICITY.

By GEORGE JAMES SYMONS, F.R.S., Hon. Sec. M.S.

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LECTURE VI.

THE NATURE, METHODS, AND GENERAL OBJECTS OF METEOROLOGY.

By ROBERT H. SCOTT, M.A., F.R.S., F.G.S., For. Sec. M.S.,
Secretary to the Meteorological Council.

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Meteorology the Science of the Atmosphere, and therefore

Stations must be multiplied to eliminate effect of local conditions—Observations must be continued for a long time to confer any value on results derived from them—Meteorology demands the knowledge of many other sciences, especially Chemistry and Physics—Determination of the amount of moisture deposited from the atmosphere, and available on the earth for mechanical work, an immediate point of contact between Meteorology and practical Engineering, etc.

Determination of the Temperature, Pressure, and motion of the Air, as well as of the changes in its constitution produced by the variations in the amount and condition of the Aqueous Vapour—Difficulties from the impossibility of extending the sphere of observations to an appreciable extent above the surface of the earth.

Objects of Meteorology almost countless—Air and its condition—Its influence on health, the growth of crops—Value of attaining the slightest approach to a knowledge of what the weather will be for even a week in advance not only to the individual, but to the country and to the world at large—Climatology as affecting the choice of colonies, and what products to expect from them—Sanitary Meteorology shows under what conditions life can best be prolonged and health maintained.

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METEOROLOGICAL LECTURES.

LECTURE I.

THE PHYSICAL PROPERTIES OF THE ATMOSPHERE.

1. Definition and Objects of Meteorological Science.

WHATEVER may be thought of the proceedings of meteorologists, there can be no rational question as to the loftiness of their aim. This is indeed expressed in the name of their science. The word Meteorology is derived from the old Greek term "μετέωρος," which signified elevated or soaring. The name has not been adopted, as it has sometimes been erroneously conceived, because meteorologists at one time busied themselves with observing the "falling stars" or "meteors." The word, as a matter of fact, was used in very much the same sense as that in which it is now applied, by Aristotle, 300 years before Christ. In a treatise which he composed under the title "Μετεωρολογικά," he dealt with all which was at that time known concerning water, air, and earthquakes. At the present time the object of Meteorology is properly the scientific study of atmospheric phenomena, and the investigation of weather and climate. The

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base of the science is, therefore, an exact and adequate acquaintance with the physical properties of the atmosphere; and these, in consequence, have been taken as the appropriate subject for the Introductory Lecture of a course, in which it is the primary aim to furnish a popular explanation of the great leading features of meteorological phenomena. In dealing with this introductory phase there is, however, one difficulty which stands in the lecturer's way. He is placed from the first, as it were, upon the horns of a dilemma, because there is danger on the one hand that he may assume too much knowledge on the part of a mixed audience, and so soar beyond the easy apprehension of one portion of his hearers; or, on the other hand, that he may render himself tedious to another portion by dwelling too much upon elementary conditions and facts. The best method to adopt in such circumstances is probably to have due regard to both sides of the dilemma, and to endeavour to steer a midway course. That, at any rate, is the solution of the difficulty which the lecturer intends to attempt upon this occasion.

2. The Invisibility and Substantiality of Air.

The air is invisible to the eye in its purest state, on account of its great transparency. It is, nevertheless, a really substantial body in itself. This is sufficiently proved by the mechanical impulse which it is able to communicate when in motion. It drives round the spirally-adjusted sails of the windmill; it forces along over the water heavily-laden ships; it strikes

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against the sensitive cheek of any person standing in its way with a blow which can be felt. But the fact is more scientifically demonstrated by showing that air has weight. If 6 cubic feet of air be condensed or compressed into an iron bottle, and the bottle be closed with a screw cap, and placed in one pan of a pair of scales, it may be so balanced there as to give the weight of the iron bottle, of the air which that originally contained, and of the additional 6 cubic feet of air which has been compressed in. If, in such a position of affairs, the neck of the bottle is unscrewed, the 6 cubic feet of compressed air rush out in a stream, and the scale pan rises as the air escapes. The counterpoise which will then have to be added to the scale to restore the balance is obviously the measure of the weight of 6 cubic feet of air. Or yet, again, a glass globe holding 4 quarts, or 100 cubic inches, may be first weighed when full of air, and then again when the air has been pumped out. The difference of weight in such case will be as manifestly the weight of 100 cubic inches of air. 100 cubic inches of air, when the barometer stands at 29·92 inches, and when the temperature is 32° Fahrenheit, weigh 32·58684 grains. A cubic foot weighs 573·53 grains. Thirteen cubic feet, or a quadrangular block measuring 24 inches in two directions and 39 inches in the third, weighs exactly 1 lb. A room 10 feet square contains 77 lbs. of air. Westminster Hall

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3. Its Gaseous State.

The smallest particles, or ultimate atoms, of air are so minute that no single one of them can be seen when in isolation from its companions. Each is smaller than the minutest speck of substance which is visible to the human eye when aided by powerful microscopes. By the help of microscopes solid particles can be seen which are only the 80,000th part of an inch across. It is certain that the ultimate atoms of air are very much smaller than that. No one can yet say how much smaller; but Sir William Thomson, who has made some very subtle investigations in regard to the molecular condition of matter, believes that the atoms of air, and of all gases, are so small that not less than 500,000,000 of them could be ranged in a line within the extent of an inch. The atoms of the air, nevertheless, are suspended many times their own diameters asunder. They do not touch each other, but float freely apart, repelling each other very energetically when the attempt is made to drive them mechanically into close quarters. Sir William Thomson has expressed his opinion that there are some circumstances connected with his investigations which seem to indicate that as many as 100,000,000,000,000,000,000,000 atoms are contained in a single cubic inch of any gas. Such figures far transcend the powers of most minds to deal adequately with them. But they help, at any rate, to impress upon the attention the fact that the atoms of the air are of an exceeding minuteness.

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4. Compressibility of Air.

It is one consequence of the atoms of air being thus freely suspended apart from each other, that they can be driven, to some extent, into closer neighbourhood by the application of mechanical force. This leads to what is termed the compression of air—the mechanical squeezing of it up into smaller volume. Air which is contained in a syringe without outlet can be squeezed in, in this way, by pressing down the piston upon it, either by the hand, or by loading it with a weight. If double the force is applied in this way to air in a closed syringe, its volume is diminished one half. This is one characteristic which distinguishes a gas from a liquid. Gas is very largely compressible, and liquid very slightly so. The pressure which would make any given volume of gas contract its bulk one half, would cause a similar volume of water to diminish only by the $\frac{45}{1000000}$th part, or about the $\frac{1}{5000}$th of its bulk. The contraction of air under pressure is, however, subject to the influence of a fixed law, which has been investigated by various able experimenters. It was examined towards the end of the seventeenth century by a Burgundian priest, named Edmé Mariotte, who dwelt at Dijon, and died there in 1684; and also by the English philosopher, Robert Boyle, who was one of the members of the First Council of the Royal Society. This law has consequently come to be spoken of indifferently as *Mariotte's* and *Boyle's* law. It applies equally to all

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kinds of gases, as well as to the atmosphere. In its simplest form of expression, it merely affirms that the volume of a gas is invariably diminished to one half by doubling the pressure to which it is exposed. It will be observed that it is a consequence of this law, that air constantly resists more vigorously as it is driven into smaller and smaller bulk, very much as a strong spring would do upon being more and more bent. A pressure of 30 lbs. upon the square inch would reduce 100 cubic inches of air into 50 cubic inches. But 60 lbs. would then only reduce the 50 cubic inches into 25.

Whenever the force which has produced condensation in a gas is removed, the gas immediately recovers its original volume, in consequence of the several atoms energetically repelling each other when they are driven into preternaturally close quarters. This property of a gas to recover its original volume when mechanical pressure is removed, is, in familiar language, termed its elasticity.

It is an important consequence of the compressibility of a gas, that in any given bulk the lower part is compressed, or squeezed in, by the weight of the atoms which rest above. Thus, in a room full of air the lower layers have their atoms squeezed more closely together by the weight of the layers which rest above.

5. Expansion by Heat.

But the compression of air by the application of mechanical force is in some measure interfered with by

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the influence of heat. Increase of temperature expands all gases. This is well instanced in the very common experiment of causing a bladder only partially distended with air to become tense and full by placing it in front of a fire. Here, again, the effect produced by the addition of heat is capable of being expressed by a fixed formula, which is termed a law, and which has been investigated by various skilful experimenters. It was independently examined by the English philosopher Dalton and the French philosopher Guy Lussac, in the years 1801 and 1802; and in a memoir upon the subject, which Guy Lussac printed in 1802, he stated that he had reason to believe the same investigation was entered upon fifteen years before by Mons. Charles, who was Professor of Physics in the Conservatoire des Arts et Metiers, and who is famous as having first employed pure hydrogen gas for the inflation of balloons. On account of this statement of Guy Lussac's it has become common, in recent times, to speak of this law of the expansion of gas as the law of Mons. Charles.[1] It is also alluded to sometimes as Regnault's law, because the French philosopher of that name subsequently improved upon Guy Lussac's experiments, and made the numerical statement of results more exact.

Guy Lussac's statement of this law was to the effect that air, and other gaseous substances, increase their volume by the $\frac{1}{489}$th part of their bulk for each

[1] See *The New Chemistry*, by Josiah P. Cooke, page 48; and *The Theory of Heat*, by Clerk Maxwell, page 29.

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degree of Fahrenheit which is added to their temperature. Regnault's correction of this gave the quantity of $\frac{1}{491 \cdot 2}$th part of the bulk for each degree, and this is now universally accepted as the more correct estimate by scientific men. When air is heated from the temperature of ice to that of boiling water, 100 cubic inches become 1366·5 cubic inches.

The kinetic, or kinematic,[1] theory of the gaseous state describes the atoms of gases as being in a condition of incessant movement, and when contained in a closed vessel as clashing to and fro in all directions and so coming into frequent collision among themselves, and continually striking against the sides of the vessel. The pressure produced upon the containing vessel by the so-called elasticity of the gas is attributed to these movements, and it is believed that the increased elasticity resulting from augmented heat is due simply to the fact that the atomic commotion is quickened and rendered more energetic by any rise of temperature. It has been calculated that atoms of hydrogen gas, under a barometric pressure of 30 inches, and at a freezing temperature, perform their kinematic dance, in this way, with a velocity of not less than 6097 feet per second.

6. Rarefaction of the Atmosphere in High Regions.

In consequence of the expansion which results in air from diminished pressure, the atmosphere gets more rare in its higher regions in proportion as it is there

[1] From *κίνημα* = motion.

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less influenced by the air-weight above. At an elevation of 3 miles, which is a trifle more than the summit of Mont Blanc, one-half the superincumbent weight has been left below, and any given bulk of air accordingly expands to double the volume which it had at the sea-level. At 6 miles of elevation the volume is again doubled. At 60 miles the air is probably as rare as the best vacuum that can be produced by the air-pump. It is quite impossible, however, for any direct observation to be made at such elevation, because no man can continue to breathe and live in air so rare. Mr. Glaisher once ascended in a balloon to 37,000 feet, or nearly 7 miles, but he was rendered insensible at a height of 29,000 feet; and he and his companion, Mr. Coxwell, owed their lives to the fortunate circumstance of the escape-valve of the balloon having been opened before actual insensibility came on. All animal life would certainly be destroyed at a height of 8 miles.

The question as to where the outward limit of the atmosphere exists, is therefore one that has to be entirely dealt with by reasoning upon theory. Some authorities conceive that there can be no air beyond eighty miles above the sea-level. In consequence of some observations recently made upon the influence of the rarer regions of the air upon twilight at Rio Janeiro, a competent investigator, M. Liais, infers that the air extends for 190, and possibly for 212, miles from the sea-level.

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7. The Weight of the Atmosphere.

The weight of the air, which has been already spoken of, is a very different thing from the weight of the atmosphere. This means, not the number of grains which any given volume of air, such as that which can be contained in a pint bottle or in a large room, weighs, but the weight with which a column of air of some definite diameter, and extending quite to the highest limit of the atmosphere, presses down upon the earth's surface. The weight of the atmosphere, in this sense, was first ascertained by the Italian philosopher Torricelli, a pupil of Galileo, about the year 1643. He took a glass tube which was open at one end and closed at the other, and which was several inches long, and turning it mouth upwards he filled it with the liquid metal quicksilver, or mercury. Then placing his finger firmly over the open end of the tube, he turned the upper end down, plunged it into a cistern or vessel filled with mercury, and then carefully removed his finger, so that the mercury in the tube and that in the cistern came into continuous contact. When the inverted tube was held perpendicularly upwards after this operation, he found that the mercury in the tube sank down until its upper end was just 30 inches above the surface of the mercury in the cistern, and then stood there, leaving an empty space at the top of the tube. He explained this curious result by the conception that the 30 inches of mercury within the tube was kept up in a balanced state by the weight

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of the column of air which pressed upon the surface of mercury in the open cistern; and his explanation proved to be correct, for when Pascal, another experimenter, caused the apparatus to be carried to the summit of the Puy de Dôme, a mountain in France some 3500 feet high, it was found that the column of mercury was there only sustained 27, instead of 30, inches, because at the summit of this mountain a tenth part of the entire weight of the column of air had been left beneath.

This experiment of Torricelli's was, in reality, the invention of the barometer, the noble instrument which is now of such vast service to meteorologists.[1]

When this experiment is performed with a tube which has a transverse area amounting to exactly 1 square inch, every 2 inches of the column of mercury in the tube weigh 1 lb. The 30 inches of the column, therefore, weigh 15 lbs. It hence appears that a column of air of 1 square inch sectional area, carried up to the very highest limit of the atmosphere, has exactly the same weight as a column of mercury 30 inches high, or

[1] The actual experiment which was performed in the first instance by Torricelli, and which led to the invention of the barometer, was of a somewhat more complicated character. A glass tube 6 *feet* long was filled with mercury, and then inserted so as to place its mouth beneath the upper surface of a reservoir of the same liquid metal, *with water covering it* to some distance above. Upon uncovering the mouth of the tube, which had been stopped by the end of the finger during the immersion, the column of mercury in its interior fell until about 30 inches above the mercurial surface in the reservoir; and when the tube was so raised that its mouth was above the mercury in the reservoir, the liquid metal at once ran down out of the tube, and the water, which still covered the mouth of the tube, then rushed up into the vacuous space until it filled the 6-feet-long tube to the top.

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in other words, that it also weighs 15 lbs. If the air-column were homogeneous all the way, instead of expanding and getting rarer with height, as it does in consequence of being a gaseous substance, it would counterpoise the 30 inches of mercury at a height of 26,214 feet, or nearly 5 miles. Air is nearly 11,000 times lighter than the same bulk of mercury. It really takes something beyond 80 miles of air to make the counterpoise, because the air is not homogeneous, but stretches itself out rarer and thinner as it gets higher and higher.

The open cistern of mercury in Torricelli's experiment was considerably larger than the closed tube holding the column of mercury; and yet the large air-column, many inches across, which pressed down upon the upper surface of the cistern, was effectually counterbalanced by the narrow mercurial column in the tube. The reason for this result is, that only so much of the air as represents a column of the same diameter as the mercury in the tube, is sustained by that column of mercury. All the rest of the air-column is supported upon the rigid bottom of the cistern. It is one of the fixed conditions of fluid pressure that this should be the case. The size of the column of mercury determines for itself how much of the air-column shall be practically brought into active antagonism, or counterpoise, with it.

The pressure of the atmosphere amounts to a very considerable force when large spaces have to be taken into account. The pressure, which is only 15 lbs.

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upon a square inch, is 2160 lbs., or nearly 1 ton, upon a square foot, and 263,000,000 tons upon a square mile. The great pressure caused by the air is familiarly shown by its bursting a bladder tied tightly over the mouth of a thick glass cylinder, when all the counterbalancing air is pumped away from beneath. 15 lbs. upon the square inch is technically spoken of as *one atmosphere* of pressure, because that is the force with which the atmosphere presses upon each square inch of the earth's surface.

The atmosphere, taken as a whole, weighs about the $\frac{1}{1200000}$th part of the entire terrestrial sphere.

The atmosphere, however, does not always press down upon the earth with the same force. There is a less weight of air over a given place sometimes than at others. When, for instance, the air gets greatly heated by the sunshine over some one spot of the earth's surface, it expands under the influence of the heat, and becomes lighter. The difference in the weight of the atmosphere from this cause amounts often to more than $\frac{1}{2}$ lb. upon the square inch. Such difference is at once indicated by the rise or fall of the column of the barometer, which stands sometimes more than an inch higher than it does at others. When the atmosphere becomes more dense and heavy, the mercurial column of the barometer rises in the glass tube, and when the atmosphere becomes rarer the column of the barometer falls. It is this rise and fall of the column of this instrument from hour to hour, and from day to day, which is termed the oscillation of the barometer.

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But over and above this, the atmosphere does not press with equal force upon different parts of the earth at any fixed instant of time. The barometer shows that the air pressure may be great at one place at the same time that it is very much less at some other place only a few miles away. There are areas of high pressure and low pressure distributed side by side over the earth.

The meteorological use of the barometer is principally confined to the measuring of these differences of atmospheric pressure, either simultaneously, as they obtain on different parts of the earth, or in succession, as they follow each other at one spot. In both instances the differences indicate conditions of the atmosphere, and alterations in those conditions, which are intimately connected with vicissitudes of weather. The barometer is employed in meteorological investigations, not to measure the weight of the atmosphere, but to ascertain the changes which occur in that weight from time to time, and the difference of that weight at different places. Wind, rain, cloud, sunny warmth, and wintry cold are all circumstances which are ruled by the varying atmospheric states indicated by these oscillations of the barometer.

8. The Glycerine Barometer.

Glycerine, or indeed any other liquid, might be used in a closed tube as a counterpoise to the column of the atmosphere, instead of mercury. But the column

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in the tube would need, in the case of such a liquid as glycerine, to be 28 feet high instead of 30 inches. Few liquids are fit for the formation of barometers, because vapour rises from them into what should be the empty space at the top of the tube, and so embarrasses the action of the instrument. Glycerine is one of the best liquids of light weight which can be employed for the construction of a barometer, because it has a vapour of low tension, which does not readily rise like the vapour of water. It does not boil until it is raised to a temperature of 290° Fahrenheit. A very ingenious glycerine barometer was actually constructed by Mr. Jordan for the recent Loan Exhibition of Scientific Instruments at South Kensington. It was fixed in one of the staircases, and the main tube was an ordinary metal gas tube, $\frac{5}{8}$ths of an inch in diameter, joined at the top to an inch-wide glass tube, in order to allow the traversing of the top of the glycerine column to be observed. The cistern was a glass reservoir, 100 times larger than the tube, and was placed at the bottom of the staircase, with a layer of paraffin floating upon the top of the glycerine to prevent it from absorbing moisture from damp air. The top of the column, and the graduated scale for noting the rise and fall of the column of glycerine, were placed on the landing-stage at the top of the staircase. A change in the condition of air which made a difference of 1 inch in the height of the mercurial column of a barometer, made a difference of 10 inches in the height of the glycerine. The barometer was, therefore, more sensitive than an ordi-

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nary mercurial one, to this extent. The specific gravity of glycerine is 1·27.

A pump can only suck water up 34 feet out of a well, because a column of water 34 feet long weighs the same as a column of the atmosphere of a like transverse area. When the pressure is lifted off the top of the pipe by the raising of the piston, the atmosphere resting upon the surface of the water in the well squeezes the liquid up into the pipe; but it can only do so until the weight of the water-column, which it has driven up into the pipe, is equal to its own pressure. A pump is, in a certain sense, a water-barometer. The water can be sucked up higher by a pump when the atmospheric pressure upon the well is high, than it can be when it is comparatively low.

9. Pressure of Air in all Directions.

The atmosphere not only presses down towards the earth by its weight. It also presses with equal force in all directions around when it is squeezed down from above. This, again, is one of the constant conditions of fluid pressure. It is due to the ready and free mobility of the atoms of fluids and of liquids amongst themselves. The pressure which acts in the downward direction is also transferred through the freely moving particles towards the side. The Magdeburg hemispheres are, for this reason, pressed together laterally when the air is pumped away from between them. A plate of flat glass is held firmly pressed up against the bottom of a glass cylinder if pressed down by it into a

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vessel of water. From this cause all bodies weigh less in air than they would do in empty space. They are sustained, to some small extent, by the upward pressure of the fluid air which they displace. A sphere of any kind, with a volume of 12 cubic inches, loses 3·1 grains of weight in air, because that is the weight of the 12 cubic inches of air which it displaces.

The most important circumstance in reference to this pressure of air in all directions around is, however, that it becomes the effective cause of the production of air movement or wind. When a heavy column of air presses down by the side of a lighter one, the air substance which lies beneath is always squeezed away from the place where the pressure is greatest towards that where the pressure is least. As cold air, of necessity, is heavier, bulk for bulk, than warm, there is thus always movement of air, or wind, from cold regions of the atmosphere towards those which are warmer and lighter.

10. The Chemical Constitution of the Air.

The air is not, however, a simple gas. It is a mixture of several different kinds of gaseous substance mingled loosely together.

The chief bulk of air is formed of two distinct gases, which are called oxygen and nitrogen. These are merely mixed loosely and mechanically in the proportions of 21 volumes of oxygen to 79 volumes of nitrogen. The atoms of the two gases float freely amidst each other, and it is a curious but well-ascer-

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tained fact that they do this with an almost entire freedom from any mutual constraint or interference. The atoms of the oxygen do not even press by their weight upon the atoms of nitrogen. They are quite indifferent to their presence, and move in the intervals between them as if they were moving in space, void of everything but themselves. This is an essential condition of gaseous existence. All kinds of gases behave themselves in this way. One kind of gas diffuses itself freely through the interspaces that lie between the atoms of another kind without suffering any obstruction from their presence beyond a very trifling retardation of their movements. The oxygen and nitrogen, under the influence of this gaseous diffusion, are evenly distributed through all parts of the atmosphere. There is the same relative quantity of each of these constituents everywhere.

11. The Aqueous Vapour of the Atmosphere.

Vapour always rises up into the air from water. Minute molecules of the water ascend into the air, and float freely about in a quite invisible state in the interspaces between the atoms of the oxygen and nitrogen. They are invisible because they are very minute in themselves, and because they are many of their own diameters asunder. The vapour state is thus physically very analogous to that of a gas. The only difference between a vapour and a gas is, that the vapour can change its state at natural temperatures from the liquid to the invisible gas-like form, and from the gas-

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like condition back to the state of liquid; whilst the gas under the same circumstances remains permanently in the thinly spread out and invisible condition. Liquid water is readily turned into thin and quite invisible vapour, and thin invisible aqueous vapour is quite as easily turned back into visible liquid.

But only a certain definite quantity of the molecules of water, spread thinly out in this quasi-gaseous or vaporous form, can be received into the interspaces of the air-atoms in this way. As soon as that quantity is reached the invisible and transparent state of the vapour ceases to be maintained, and the molecules begin to aggregate together so as to present themselves to the eye as visible mist. In other words, the vapour begins to be deposited as water, and to fall through the air. Whenever it happens that the interspaces of air hold the full charge of vapour which it is capable of sustaining in the invisible state, such air is said to be saturated with invisible moisture.

Warm air, however, is not so easily saturated with moisture as cold. The warmer the air is the larger the quantity of invisible vapour that it can sustain stored away in the interspaces that lie between its atoms. Thus, air at the temperature of 32° Fahrenheit can sustain the $\frac{1}{100}$th part of its own weight of transparent vapour; at the temperature of 59° the $\frac{1}{80}$th part of its weight; and at 86° as much as the $\frac{1}{40}$th part of its weight. In other words, for every addition of 27° of temperature the capacity of air to sustain invisible vapour is doubled.

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The height of the column of the barometer gives the combined weight of the oxygen and nitrogen gases of the air, and of the aqueous vapour; that is to say, each one of these constituents produces an effect in lifting the column of the barometer.

Fully saturated air at a temperature of 32° Fahrenheit contains only 2·37 grains of aqueous vapour in each cubic foot. Saturated air at a temperature of 60° contains 5·87 grains in each cubic foot; and saturated air at 80°, 10·81 grains. If, therefore, at any time fully saturated air, with a temperature of 80°, is suddenly chilled to 60°, very nearly 5 grains of water are thrown down out of each cubic foot. Such really is the effective cause of rain. Warm air drinks up as much invisible vapour as it can hold, floats it away on the wings of the wind, and then, when it reaches some colder place, throws a considerable portion of it down in actual droplets of water.

Evaporation of water into the air is increased, it is to be understood, to some slight extent by low atmospheric pressures, and is also favoured by wind, which sweeps the vapour away as it rises. So again, on the other hand, the production of air movement, or wind, is in some sense facilitated by the mechanical influence of rising vapour.

12. The Cooling Effect of Evaporation.

Each grain of water, when it is turned into vapour, carries off with it sufficient heat to raise 960 grains of water 1° Fahrenheit. That much heat is conse-

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quently taken away from the water. The water from which the vapour ascends is cooled to that extent. The heat, however, is not lost. It is merely absorbed into the vapour, and retained there in a latent or sleeping state; that is, in a state in which it is no longer capable of producing an effect upon the thermometer, or of exciting the sensation of warmth. It is employed, whilst retained in that latent state, in maintaining the thin and expanded condition of the vapour; in keeping its molecules floating loosely and widely apart, instead of in producing the sensation of warmth. The whole heat, however, is given back to the air in a sensible state, when the vapour is again condensed into water. This is one reason why the occurrence of rain is so frequently accompanied by an elevation of the air temperature.

13. The Cooling Effect of Rarefaction.

In ascending into the higher regions of the atmosphere, as in climbing a lofty mountain, it is found that the air continually gets colder and colder with the ascent. This is due to two influences. First, the higher the region, the farther it is removed from the warm ground, which is the principal source of the heat communicated to the air. The sun's warmth is given first, not to the air itself but to the solid ground, and the air is then warmed by touching the ground, and by floating away with the heat which it receives. But over and beyond this, as the air expands under the diminution of pressure in the higher regions, it absorbs

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sensible heat to maintain the expansion of its own substance, and renders that latent and insensible. The air itself thus becomes cold in consequence of its warmth being taken away from it for use in a different way. Heat is always absorbed and rendered insensible during the rarefaction of a gas; and is invariably developed and made sensible during its condensation. Enough heat can be produced to set fire to a piece of tinder by squeezing air suddenly down in the inside of a closed syringe.

The outermost limit of the atmosphere gets cooled down by rarefaction probably to $-77\frac{1}{2}°$ Fahrenheit over the equator; and to $-119\frac{1}{2}°$ over the poles.

14. Diathermancy of Dry Air.

The solar rays pass through pure dry air without warming its substance at all. The air is, so to speak, transparent to heat. That peculiar property is termed diathermancy.[1] Professor Tyndall has shown, by direct experiment, that dry air, and indeed the gases nitrogen, oxygen, and hydrogen are as freely permeable to heat as a vacuum or empty space.

15. Heat-absorbing Power of Aqueous Vapour.

Aqueous vapour, even when in its most invisible and transparent state, on the other hand, acts as a powerful screen to the heat rays of the sun, arresting them in itself, and preventing them from passing freely on. This is a very important fact. The àqueous

[1] From διά, through, and θέρμη, heat.

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vapour of the atmosphere not only stops a good part of the sun's warmth before it reaches the earth, but also further acts in keeping the warmth there when it has once struggled through as far. Professor Tyndall has shown that 10 per cent of the warmth which is radiated back from the solid surface of the earth, through moist air, is arrested within 10 feet of that surface. The sunshine on mountain tops scorches very severely, because the air above them is too dry to afford any screen from the heat. But the heat of low-lying places, even in the tropics, is not scorching, but soft, because there its greatest force is intercepted by the abundant vapour that is sustained in the lower strata of the air.

Professor Tyndall thinks that the rain deluges which often fall in tropical calms are partly due to the powerful radiation of the heat through the dry air which rests above the lower region of great moisture. He conceives that the ascending column of fully-saturated air expends its heat by free radiation when it gets above the dense vapour-screen of the lower elevation, and that the superfluous vapour is then condensed by the chill, and thrown down as a copious torrent of rain. The formation of cumulus clouds may be ascribed to a similar cause. The visible vapour is formed where the radiation goes on most vigorously through the rare dry air above. Professor Tyndall very expressively speaks of the cumulus cloud as the capital of an invisible column of saturated air. Mountain tops gather clouds around them for the same reason; they cool themselves by radiat-

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ing their heat, through the dry superincumbent air, into space; they also, of course, increase this effect by deflecting moist winds up towards their summits, and by causing them to expand and deposit their moisture, as they rise, under the diminution of pressure. Even over the torrid desert of the Sahara the nights are comparatively cold, and the daily range of temperature is large, because the air is there exceedingly dry and clear, so as to permit very powerful radiation at night.

It must hence be understood that a clear, cloudless, starlit sky, is not *necessarily* a good medium for the radiation of terrestrial heat. For that purpose its air must be dry as well as clear. A moist clear air acts effectually as a heat screen.

16. The Carbonic Acid and Ammonia of the Atmosphere.

Two other gaseous substances are found constantly present in the interspaces of the air-atoms, mingling their molecules with those of the aqueous vapour, although in very much smaller proportional amount. These are the compound gases which are known as carbonic acid and ammonia, and which are poured continually into the atmosphere by the decomposition and combustion of organised structures. Their quantity is, indeed, so small that no account is taken of their presence by the barometer. The proportion of the pressure which they produce is so slight that it is overlooked in barometric results. There are about 3·36

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gallons of carbonic in every 10,000 gallons of air, and a trifle more than the same quantity of ammonia in 10,000,000 gallons of air. Small as these proportional quantities are in themselves, they are, nevertheless, capable of yielding very considerable supplies when large spaces of the atmosphere are concerned. The air which rests upon 1 square mile of land at any instant, contains in itself not less than 1,300,000 tons of carbonic acid, and therefore as much as 371,475 tons of the solid element carbon, converted to the gaseous state by its combination with oxygen. The rain carries down, every year, to each acre of ground, 30 lbs. of ammonia, although, on account of its great solubility, this gas is 1000 times less abundant in air at any one time than carbonic acid.

17. The Nature of Ozone.

A peculiar odour is developed in the atmosphere, chiefly through the influence of electrical discharges of high intensity, and by the evaporation of water, which has been referred to the production in small quantities of a distinct substance, which, in consequence of its peculiar smell, was named ozone by Professor Schönbein of Basle, in 1840.[1] It exists in very small proportional quantities in the atmosphere, even when most largely developed. There is rarely more than 1 gallon of ozone in 700,000 gallons of air.

It is now known, however, that ozone is not a distinct substance, but merely a condensed and excep-

[1] From ὄζω, I (have a) smell.

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tionally active condition of oxygen. Dr. Andrews succeeded in demonstrating, by direct experiments in 1856,[1] that ozone is simply oxygen condensed to the extent of one-half of its volume, and that it can be turned back into oxygen by exposing it to high temperatures. Ozone is distinguished by its very high oxidising powers. It destroys the mobility and bright lustre of metallic mercury, removes potassium from its neutral combination with iodine, thus leaving the latter element free to produce its characteristic blue colour with starch, and it rapidly decomposes most organic substances. In densely peopled towns there is, on this account, an entire deficiency of ozone in the air; but it is generally present in full quantity in the air of open country districts, and still more especially in the neighbourhood of the sea.

18. The Transparency of the Atmosphere.

Pure air is freely permeable to the vibrations of light; they pass through amidst the atmospheric atoms very nearly as freely as they would through blank space. The diathermancy and transparency of the atmosphere, it may be remarked, are of the very highest importance to the existence of living creatures upon the earth. In consequence of the diathermancy of the atmosphere the heating power of the sunshine penetrates down to the terrestrial surface to produce the various molecular activities and changes upon which vital operations depend. The transparency of

[1] See *Philosophical Transactions of the Royal Society for* 1856.

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the air opens the window of the earth, so to speak, first for man's outlook into the surrounding regions of space, and secondly for the admission of those wonderful effects of light which render terrestrial objects visible, and which clothe their surfaces with beautiful diversities of colour, and of brilliancy and shade. It only needs that London should be thought of as it exists in a dense November fog, for a very vivid idea to be presented to the mind of what the earth would be without the diathermancy and transparency of its atmospheric investment. It is a noteworthy fact that aqueous vapour in its most elastic state does not arrest the luminous vibrations as it does the vibrations of heat. It is as transparent to light as pure air itself.

As soon, however, as aqueous vapour begins to be condensed into visible mist its permeability, by the vibrations of light, is destroyed. The gorgeous colours which appear over the western horizon after sunset are due to even the strongest vibrations of light,—those, namely, which produce the impressions of yellow, and orange, and red,—not being able to penetrate freely through those portions of the atmosphere which are then more or less laden with mists and clouds. The yellow and red vibrations are caught by the gathering mists and turned back to the surface of the earth, and to the eyes of observers there placed. Even in its purest state the atmosphere appears to be not quite as freely permeable to the vibrations of light as it is to those of heat. The blueness of the so-called sky is in reality due to the faint blue vibrations reflected up from

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the earth being caught by the air-particles and vapour-molecules which are crowded up behind each other for mile after mile in the atmosphere. The atmosphere is blue overhead, because it is able there to arrest and turn back to the eye the blue vibrations of light which are struggling out through it towards external space. Air is a blue medium really when the vast depth of the atmosphere is taken into account, instead of being absolutely colourless and absolutely clear. In ascending to the higher regions of the atmosphere the sky continually assumes a deeper and darker blue, because with each additional stage of ascent there remains less air-substance above to arrest and turn back the blue vibrations.

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LECTURE II.

AIR TEMPERATURE: ITS DISTRIBUTION AND RANGE.

THE subject on which I have the honour to address you this evening is one that may perhaps be considered as trespassing somewhat on the domain of geography. I will not admit the trespass; but I will readily admit that not only this, but a great deal of meteorology, is very closely related to that branch of geography which seeks, by reference to Physical Science, to illustrate or interpret the facts observed in different parts of the world. I should be sorry, indeed, to think that meteorology was limited to reading off thermometers, or making other exact measurements; just as I should be sorry to think geography was nothing more than exploring, surveying, or map-drawing. If geography is to be understood as the study of the earth and all that belongs to it, it embraces meteorology, which is the study of the superincumbent air—that air which we breathe and in which we live. But in any case, the two sciences, if not united, are so connected, as to be at many points inseparable. Of these, the study of climate is certainly one; for if anything happens to make us personally interested in any place, the very first questions we ask concerning it are as to the

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climate. To the half-intending settler these are everything:—Is it healthy? is it wet? is it dry? is it hot? is it cold?—these are the questions which principally fix his purpose. There are, doubtless, many other points which have their own weight: good harbours, a ready market, a teeming soil, luscious fruits, heavy grain crops, succulent grasses: but though even these are but another way of stating some of the conditions of climate—rain, sunshine, or tempest—though they have thus a direct meteorological bearing, they are still, by themselves, not those to which a man trusts, I do not say his own life, but the lives of those most dear to him; and they fade into insignificance before that most vital of all questions—Is the place fit to live in? The answer involves a special examination into the nature of the air; and though this may, in some respects, require instruments more sensitive than man can yet make—may require, for instance, the delicate organisation of man's own body to detect the subtle miasma which gives ague or low fever; in others, again, it can be made with almost mathematical precision, and the peculiarities of the climate portrayed as on a map. Amongst these peculiarities, capable of investigation, and falling distinctly within the scope of meteorological science, one of the most important is the temperature. But it is not only in regulating the more serious affairs of life that questions of temperature come before us; they crop up continually; they belong to the bath-room or the greenhouse; I have heard them mentioned in the theatre or the ball-room;

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and the street stalls, selling halfpenny ices, appeal to a taste which clearly requires no cultivation. Thus, then, economically or socially, temperature has an interest for us which begins at our birth and ends only at our death; and it is perhaps on this account, almost as much as on account of its importance as a factor in other atmospheric conditions, and as related to changes of weather—wind and rain—that the Council of the Meteorological Society has placed it first on the list of the special subjects included in these Lectures.

Of the different sources of heat, and of the several modifications which heat, when once excited, can undergo, it does not fall to me to speak. So far as climate is concerned, all heat emanates directly or indirectly from the sun. If the sun were extinguished we should have no heat at all. It is difficult to conceive such a state of things. Absolute zero, the temperature at which air is supposed to lose all its elastic force, has been estimated as about 500° of Fahrenheit's scale below the freezing point of water; as far below it, that is, as the temperature of melting lead is above it. But whether the so-called absolute zero is any measure of the absence of all heat is, and so far as we can see must remain, unknown. It may possibly represent the temperature of interstellar space. Some writers have supposed that it does; others have supposed space to be very much colder; others, again have conceived that, warmed by distant stars, it is not nearly so cold, and have estimated it at about 270°

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below freezing point. All this, however it may be veiled, is mere guess-work. The only limit, based on trustworthy experiment, is the absolute zero; and failing any more definite interpretation, I should be inclined to accept 500° below freezing point as a rough approximation to the temperature of space.

The earth itself has often been spoken of as a source of heat; for it is very certainly known that in deep borings the temperature increases at a rate which may be estimated as about 1° in every 55 feet. But this purely terrestrial heat is no longer sensible at the surface of the earth, and has nothing whatever to do with climate. Climatic heat comes solely from the sun, and without the sun we should have everywhere a temperature if not of absolute zero, at least far below any of which we have a natural experience; far below any ever observed either in Siberia or in the high northern latitudes beyond Smith Sound.

Since, then, the sun is the source of all climatic heat, it would seem at first sight as if all places on the same parallels of latitude ought to have the same temperature; as if the decrease from the equator towards the poles should be regular, and everywhere the same. That this is not the case is well known to you all; is a matter of familiar personal experience; for the fact is that the temperature of different regions on the face of the earth depends on a great many conditions, of which latitude is undoubtedly one; but except over extreme distances, by no means a very important one.

If we mark on a map the mean temperature of as

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many places as possible, either for a month, or a season, or a year, and join all those which have the same temperature, the lines so drawn are called isotherms —lines of equal heat; and the maps on which they are drawn are called isothermal maps. The suspended map shows, in different colours, the isotherms for January, for July, and for the year; and you will see almost at a glance how widely, how irregularly, they differ from the parallels of latitude. It is evidently quite impossible to say that any particular temperature belongs to any particular latitude at any particular season; it is quite impossible to calculate from the position of the sun and the latitude what the temperature at any place ought to be; though this was long a favourite idea. All that we can do is by actually observing a great number of temperatures at different places on any one parallel, and taking the mean of them, to form, from that, some idea of the temperature belonging to that parallel. The mean temperature so found has been called the normal temperature of the latitude; and the temperatures which differ from that mean are abnormal. If we mark on a map, at a number of places, the extent of the difference from the normal, and join those in the same neighbourhood that have the same difference, the lines so drawn are called isabnormals, and the map becomes like these now before you; where the blue colour shows the parts below the normal temperature, and the brown those that are above it. Such maps are interesting, as showing, from a different point of view, the very slight connection between

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latitude and mean temperature; but beyond that they have but little signification, and the normal referred to is altogether artificial.

What, then, is the reason of this very marked irregularity? Of mere local causes, the most important is what we commonly know as aspect. A place fronting towards the mid-day sun, on the side of a slope, sheltered from cold winds by a line of hills or high land, or even a clump of trees, is often found to be very much warmer than other places, in the same neighbourhood, but less favourably situated. Many of our south coast watering-places are familiar examples of this: Ventnor and Torquay to an almost extreme degree. As far as mere sensation goes, between the Undercliff on a fine July afternoon, and Queen's Road at Hong Kong, I don't know that there is much choice. Aberdour, on the south coast of Fife, is another somewhat similar locality, where, sheltered and warmed by a low cliff, geraniums and veronicas may be seen in full flower at Christmas or the New-Year. The same cause acts of course in every part of the world. As compared with neighbouring localities, the temperature of any place depends almost entirely on its aspect and shelter. Examples of this will occur to every one; but, as a very marked instance of the force of mere aspect under the most difficult circumstances, I may refer you to Sir George Nares's notice of a little lake near the "Alert's" winter-quarters, which, though 500 feet above the sea, showed no sign of freezing, when the temperature at

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the sea level had fallen to 28°, and no water was to be got on the lowlands.[1]

This reference to Arctic observation reminds me of another and rather curious cause of local differences of temperature. When water is turned into ice a great deal of its contained heat is—so to speak—squeezed out of it; its molecular energy is transferred to the surrounding air, and is dispersed. But when this is done on a large scale, it may and does produce a marked and apparently paradoxical increase of temperature, and for the moment soften the rigour of an arctic climate; an effect which has been more especially noticed in Siberia, as accompanying the freezing of the sea, and the lakes, and the rivers, in October.[2] Thawing acts in exactly the opposite way; for ice, as it is converted into water, absorbs a great deal of the surrounding heat, and lowers, or tends to lower, the general temperature. It is thus that, within the Arctic, those localities which, by the configuration of the land and the set of the tides or currents, are permanent ice-traps, have an exceptionally severe climate. Melville Bay may be named as one of these. Rensselaer Bay—Kane's quarters for two miserable winters—is another; whilst Port Foulke, between the two, is described as mild in comparison. The difference is to be attributed not to the mere presence or absence of ice, but principally, perhaps, to the fact that ice formed in the one

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1 *Voyage to the Polar Sea*, vol. ii. p. 142.

2 Wrangell's *Expedition to the Polar Sea*, p. 48 (2d edition, by

place where it gave out its heat, and floated away to thaw and absorb heat in the other.

When from smaller, or, as they may be called, more purely local causes, we pass on to larger or geographical, the most patent are the differences of soil, or geological conformation. The sun shining on the air does not heat it to any perceptible degree; the direct heat of the sun passes through air, as its light passes through glass; but when it warms the surface of the earth then the air is warmed by actual contact, by convection, or radiation. This may perhaps be a new idea to some of you. If the heat, as it radiates from the sun to the earth does not warm the air, why should it warm the air either by contact with the ground or as it radiates from the ground? It is that the character of the heat is changed; that its waves, which were short and quick in their vibrations, are now long and sluggish. Heat, radiating from an obscure source, is stopped by air, and more especially by damp air, in much the same way that obscure heat-rays are stopped by a glass screen placed in front of the fire. Another familiar illustration of the same peculiarity is given by the stifling heat of a room when the sun shines full on its closed window; and still more by the heat of a conservatory: the luminous heat-rays pass in through the glass; the obscure heat-rays cannot pass out; the room, or the conservatory is thus a very heat trap. The heat of the sun can in this way be collected to an extent that seems almost incredible. If a box, lined with some dark-coloured non-conducting substance—as for instance, with black silk

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quilted with wadding, or with black wool—and the top of it closely covered with two or three slabs of clear plate glass, be placed facing an English July sun, the temperature will rise far above that of boiling water; a small vessel of water placed in it will boil briskly; but the difficulty of carrying off the steam has (I believe) prevented this way of catching heat being turned to any economical use. Such boxes have been, and still sometimes are fitted up, with the idea that the observed temperature inside them is a measure of the intensity of the sun's rays. The idea is quite a mistake. Very high temperatures are often observed in them, but they are a measure of nothing at all, unless indeed it be of the security of a useless trap.

Now it is just in this way that when the sun, shining through the air, strikes on ground easily warmed—that is, with small capacity for heat—such ground communicates the heat to the air both by contact and by radiation; the heat is obscure, and cannot pass freely through. But when, on the other hand, the ground is such as is not easily warmed, has—that is to say—a large capacity for heat, it holds to what falls on it; and, in some way, converts it to energy within itself, and the surrounding air receives but little. Of this nature are lands covered with grass or other vegetation; and, to a still greater degree, the snow-clad plains of high latitudes, or the slopes of lofty mountains. One of the many marvels told by Arctic travellers is of the intense heat of the sun blistering black paint, or making the pitch boil and bubble up

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from the seams of the ship's deck, whilst the snow is lying thick all around, and the air in the shade has a temperature far below freezing point. On the high Alps, or on the Himalayas, similar experiences have been recorded. Professor Tyndall has told us that above the grand plateau of Mont Blanc, he has felt the heat of the sun well-nigh intolerable, although at the time hip-deep in snow; and Sir Joseph Hooker, amongst other curious observations in the Himalayas, saw, one December morning, at a height of 10,000 feet, the mercury, in a black bulb thermometer exposed to the sun's rays, mount to 132°, whilst the temperature of shaded snow hard by was 22°. Such heat of course falls on the snow; but a great deal of it is at once reflected, and what is not is absorbed by the snow; possibly in liquefying some little, which is shortly afterwards again frozen, and the heat dispersed.

Very different is the action of the sun's heat when it falls on sandy or stony ground, which is easily warmed and as easily parts with its warmth. The resulting effect of this is very familiarly known; and the extreme mid-day heat of the great deserts, whether in Asia, or Africa, or America, or Australia, as compared with that of many other places nearer the sun, is but a larger and intensified example of the action of the same cause that makes us prefer, for a summer walk, a country field path to a white macadamised road.

The observed temperature, on some occasions, at desert stations, is almost incredible. At Murzuk, an oasis of the Sahara, an air temperature of 130°, and

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even a degree or two more, has been noted. At Cooper's Creek, a spot rendered classical, in the history of Australia, by the deaths of those gallant explorers Burke and Wills, a thermometer, which was marked up to 127°, burst whilst lying in the sheltered and shaded fork of a tree; how much more than 127° the temperature was at the time was undetermined. Many similar instances might easily be collected from the experiences of travellers in the deserts; they are by no means rare; but they must nevertheless be considered exceptional; for their domain, however large, is small as compared with the area of the globe's surface.

More important, by far, from a geographical point of view, are the prevailing winds of any locality, and their relations to the ocean currents in its neighbourhood. Heat or cold may be, and often is, carried into a country by wind which has gained or lost warmth in passing over burning soil or snow-covered regions. The air is indeed the receiver and transmitter of all the heat that makes the earth habitable; without the air and the clouds of vapour in it, the heat, as soon as it strikes the earth, would be radiated back again into space; it is by the air that it is confined and rendered available for the support of life. The air has thus, in the economy of Nature, a use almost as important as that of oxygenizing our blood. Necessary as the air is for us to breathe, it, or some other gas in its stead, is equally necessary to warm us.

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But notwithstanding this importance of air, great as

ocean: the effects of wind are mainly due to the ocean currents, for though it is by the wind that the warmth is carried over the land, it is from the ocean that it gets that warmth; it is by the currents of the ocean that the warmth is carried from low to high latitudes; it is by the currents of the ocean that arctic cold is carried into the tropics.

The power of dry air to carry heat is trifling as compared with that of the same volume of water. In scientific language, water has a much greater capacity for heat than air has. The quantity of heat that would raise by 1° Fahrenheit the temperature of a cubic foot of water, would raise by 1° the temperature of 3234 cubic feet of air; or, which amounts to the same thing, would raise the temperature of a cubic foot of air by 3234°. The water absorbs the heat and carries it about wherever it goes; the air, on the other hand, can hold but little, and throws it off into space at the first opportunity. Air, in contact with a heated soil, may be raised to a high temperature, much higher than water is ever raised to by the action of the sun: I have already said that the air is occasionally raised to a temperature of more than 130°; the water of the sea perhaps never exceeds 85°: but the water, nevertheless, contains a very much greater amount of heat, and can carry it to much greater distances. It is by reason of this that ocean currents have the enormous climatic effect familiarly attributed to them. The Gulf Stream has been so often talked of, that it has been voted a nuisance; it is a nuisance that we

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could very ill do without. Its climatic effect, when stated in measures of heat, is stupendous—it is the very poetry and romance of arithmetic; and perhaps you may think that a thing that can get poetry out of the multiplication table is marvellous indeed.

The heat brought by the Gulf Stream into the North Atlantic has been fairly estimated as not less than one-fifth of the whole heat possessed by the surface-water of that division of the ocean. Now Sir John Herschel, and other eminent writers, English and French, have estimated the temperature of space at 239° below zero; it is, as I have said, probably enough, considerably lower. If with this we compare the existing temperature of the North Atlantic, which may be taken as 56° above zero, we find that the heat which it actually has corresponds to a temperature of 295°, the fifth part of which is 59°. If then, the fifth part of its heat, the heat derived from the Gulf Stream, were taken away from it, the surface-water of the North Atlantic would have an average temperature of 3° below Fahrenheit's zero, or 35° below the freezing point of fresh water.[1] Such a calculation may appear almost wild, but it errs, if anything, in allowing too much heat. I am by no means sure that, instead of 35° below freezing point, I ought not to say nearly 100°.

Another way of considering the effect of the Gulf Stream leads to a result scarcely less startling. A quantity of water, which may be roughly estimated at

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about five billions of cubic feet, is hourly poured through the Straits of Florida into the North Atlantic. This water has then an average temperature of not less than 65°, and after performing a circuit in the North Atlantic, returns to the tropics with an average temperature of not greater than 40°. It gives out to the air of the North Atlantic the heat corresponding to a difference in temperature of 25°. Now, if you will remember that our standard measure of heat—the British thermal unit—is the quantity of heat necessary to raise the temperature of 1 lb. of water by 1°, and that a cubic foot of water weighs about 64 lbs., you will see that the heat so thrown out every hour into the air of the North Atlantic is $25 \times 64 \times 5{,}000{,}000{,}000{,}000$ thermal units.

Such a row of figures conveys little meaning; I will try to make it more intelligible. Every thermal unit, when converted into power, is capable of lifting a weight of 772 lbs. through a height of 1 foot—this is the law of equivalence, experimentally established by Dr. Joule of Manchester. Consequently, the heat hourly dispersed from the water of the Gulf Stream, if stored up and applied as power, would be capable of lifting, each hour, $772 \times 25 \times 64 \times 5{,}000{,}000{,}000{,}000$ lbs. through a height of 1 foot; that is, of doing the work of steam-engines having an aggregate horse-power of 3,119,000,000,000—a power equal to that of nearly 400,000,000 ships such as our largest ironclads.[1]

Numbers such as these, however vague they are in

[1] *Climate and Time*, p. 25.

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themselves, and perhaps even by reason of their vagueness, will serve to give you some idea of the enormous quantity of heat carried by the Gulf Stream. This heat is dispersed into the overlying air, and in it is wafted by the south-westerly winds over the north-western parts of Europe, and in a very large proportion over our own favoured country. It is this that makes the astounding difference between the climates on this side the Atlantic and on the other; it is this which gives us here our green fields and open harbours through the winter, when Labrador, and Newfoundland, and New Brunswick, in the same or lower latitudes, are buried beneath snow, and when the Gulf of St. Lawrence is choked with ice.

But notwithstanding this great difference, a considerable share of this heat given out by the Gulf Stream, is spread abroad over North America, a considerable share is carried into the Arctic circle; and their climates, however rigorous they actually are, are less so than they would be if there was no Gulf Stream. Other currents, whether hot or cold, act all over the world in a similar manner; you can trace their effects on the isothermal or isabnormal maps before you; they carry away excess of heat from one place, excess of cold from another, and everywhere tend to mitigate the extreme degree of either. It is difficult to exaggerate their importance; and indeed Mr. Croll, one of the most earnest and able exponents of this branch of geography, has summed up his arguments and calculations in the incisive sentence, "without ocean currents the globe

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would not be habitable." The function of the two great oceans—the Atlantic and the Pacific—is, he concludes, to remove the heat from the equator, and carry it to temperate and polar regions. Aerial currents could not do this. They might remove the heat from the equator, but they could not carry it to the temperate and polar regions; it would be dissipated into stellar space. The ocean alone can convey it to distant shores. But aerial currents have, nevertheless, a most important function: it is theirs to distribute over the land the heat brought, by the ocean currents, into the higher latitudes, and on the one, as on the other, depends the thermal condition of the globe.[1]

This mutual action of the great currents of air and water, their relation one to the other, has not, I think, been fully realized, even by some of our most eminent writers. Sir John Herschel himself has said,[2] "The effect of land under sunshine is to throw heat into the general atmosphere, and so distribute it by the carrying power of the latter over the whole earth. Water is much less effective in this respect, the heat penetrating its depths and being there absorbed; so that the surface never acquires a very elevated temperature, even under the equator." In writing thus he clearly overlooked, for the moment, the great carrying power of water; overlooked also the very small carrying power of air; but when a man such as Sir John Herschel has made this mistake, it is not to be wondered at that others have repeated it; have spoken of wind as the principal

[1] *Climate and Time*, p. 51. [2] *Outlines of Astronomy*, sec. 370.

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or only agent in transferring heat from one place to another, and have ascribed to hypothetical volumes of hot air phenomena which, under the circumstances, they could not possibly produce.

One favourite instance of this is a reference to the retrocession of the Swiss glaciers, which were formerly of very much greater size, as is proved by the positions of the old terminal moraines. It has been urged over and over again that this former vast extent was due to the fact, that what is now the Sahara was then the bed of the sea. Air passing northwards would not then, it has been said, carry with it the heat that is now brought from the sandy desert. The hot wind which does come from the sandy desert, known to all Mediterranean travellers as the Scirocco, has many curious and disagreeable properties; but as a set-off, it has been supposed to soften the climate of Switzerland, and to cause the glaciers to creep back to their present comparatively small size.

This claim in favour of the Scirocco cannot be allowed. Whatever redeeming qualities it may have—and I know of none—it certainly has not this: when it strikes the shores of Genoa or Provence, it is no longer a markedly hot wind, and it has no relation whatever to the peculiar hot wind of Switzerland, known locally as the Föhn, which, in a careful examination by several Swiss meteorologists, and especially by Dr. Wild,[1] now the Director of the observatory at St. Petersburg, has

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south-westerly winds of the North Atlantic, carrying inland the warmth and moisture of the Gulf Stream. But the way in which these are converted into the very remarkable dry heat of the Föhn deserves special notice.

The Föhn, as such, is known only in the north-eastern valleys of Switzerland,[1] and it is there distinguished by its great heat, and, still more, by its peculiar dryness, before which the snow disappears, both by rapid melting, and also by that rapid evaporation which has obtained for it the appropriate name of the snow-eater (Schneefresser). But whilst the Föhn proper is blowing in the valleys of the north-east, eating away the snow in winter, or in summer and autumn drying the hay and ripening the grapes, over the south-west of Switzerland a warm and wet wind blows, which precipitates its moisture in a heavy down-pour, and floods the country with rain and melted snow. The connection between these two has been clearly traced only within the last few years. When air is driven or lifted to a great height, as by being pressed up a mountain slope, the expansion of its volume causes a corresponding lowering of its temperature, and the air which approaches the mountains on the west should experience a certain definite loss of temperature whilst being lifted to the mountain-tops; the amount of which may be easily calculated by a reference to the height of the mountains and the diminution of barometric pressure. But if the

[1] The distinctly Föhn stations named by Dr. Wild are Glarus, Auen, Altdorf, Engelberg, Schwyz, Chur, and Klosters.

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air is moist, the chilling, to which it is thus subjected, condenses the vapour, causing heavy rain on the windward, that is the western, slopes. Now, vapour, when turned into water, gives out a great deal of heat; the heat which it has previously absorbed, which gives it molecular energy, and which is very commonly known as latent heat; and this heat, set free, warms up the surrounding air; so that the temperature at the mountain-top may be, and is, many degrees higher than, according to the calculation based on the loss of barometric pressure, it ought to be. If now, this air, with the moisture squeezed out of it on the mountain-tops, and its temperature raised by the heat of condensation, is forced down into the valley beyond, the increase of pressure, as it goes down, raises the temperature by an amount depending, as before, on the height from which it has descended, and on the rise of the barometer; so that the air comes into the valley with the temperature due to the level at which it has arrived, increased by the heat conveyed to it, on the mountain-tops, by the condensation of the vapour. The air is thus not only very hot, but relatively also very dry; that is to say, on the descent of the Föhn the temperature rises, at times, to more than 80°, and the humidity sinks to about one-fourth of what the air is capable of holding.

Of the Swiss Föhn, such as I have described it, many here may have personal experience; but a wind similar to it in its peculiar warmth and dryness, is observed on the lee side of many mountain ranges.

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eastern settlements of New Zealand; Professor Mohn speaks of it as frequent in Norway; it is not uncommon in the Danish stations of Greenland. Three times during the February of 1860, the temperature at Jacobshavn rose through more than 45°, with a south-easterly wind; it was observed on board the "Fox" in her celebrated drift down Baffin's Bay in the winter of 1857, on the 22d of November, when the temperature rose through 39°. Even so far north as the winter quarters of the "Alert," such a warm south-easterly wind blew occasionally; and once at least, on the 3d of December 1875, the temperature rose, within a few hours, through 43°, from 8° below zero to 35° above it, a temperature higher than that of any water within 600 miles of the ship's position; whilst at the mast-head, away from the cooling influence of the snow, it was found to be some 3° higher still. This was at first supposed to be a simple warm blast from the south; that it was not so was known afterwards by a comparison with the observations on board the "Discovery," 46 miles farther south, where the wind continued north-westerly, and the temperature during the day was never higher than 4° above zero.[1]

In North America, again, the soft wind from the Pacific descends on the eastern side of the Rocky Mountains hot and dry. It is this that gives the peculiar character to much of the scenery of the far

[1] Russell's *Climate of New South Wales*, p. 17. Wild's *Ueber Eiszeit, u.s.w.*, p. 56. *Nature*, vol. xvi. p. 294. M'Clintock's *Voyage of the "Fox,"* p. 70. Nares's *Polar Sea*, vol. i. pp. 203-7; and Moss's *Shores of the Polar Sea*, p. 49.

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west; not, as might be supposed, by its climatic effect, but by the great fires which it renders possible. The wind blowing often for several days in succession, greedily drinks up moisture from every source; the pine timber of which houses, barns, fences, etc., are built, becomes excessively inflammable; the weeds and grass of the prairies become so much tinder; and a flash of lightning, or a spark from a camp fire, a pipe, a gun wad, a passing locomotive, is sufficient to light a fire that may spread over a county. It is thus that those fires begin which have been familiarly known in the great prairie region of the Mississippi, ever since its first exploration, and which are themselves the true cause of the prairies—a distinctive feature of North American geography. These have, indeed, been commonly attributed to some peculiarity of the soil; but it seems quite certain that, when protected from fires, trees flourish there as well as anywhere else; and towards the northern boundary of the prairie region, where the limit of this peculiar dryness sways backwards and forwards from year to year, a constant struggle is maintained between the two conditions of forest and prairie, which gives rise to those beautiful and park-like patches of landscape, celebrated as "oak-openings."[1]

But hot winds of this kind are clearly of a totally different nature from those which derive their heat directly from the burning soil of a desert, such as the

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Scirocco, or the Hot-Wind of Sydney or Melbourne, or others experienced in Arabia, Persia, Beluchistàn, the Punjàb, on the West Coast of Africa, or elsewhere; winds which may perhaps be explained as the escape of air in a state of exceeding tension from an envelope of other air rendered viscous by the action of heat.[1] Some such mode of escape has been well described by that able naturalist Mr. Thomas Belt, whose early death is a loss to almost every branch of physical science:[2] and though Mr. Belt's observations are rather of air forcibly expanding upwards through a rent in the overlying stratum, I see no reason to doubt that it may—under favourable circumstances—expand sideways in a very similar manner.

In their general effects, cold winds are often still more marked than the hot; even at Sydney, disagreeable as the Hot-Wind is, the cold southerly burster that follows it is almost as bad: the cold wind that, frequently during winter, sweeps the continent of North America from north to south, is more deadly than any hot wind, even than the half-fabulous Samiel or Simoom. The snowstorm which such a wind brought over Minnesota in January 1873—a snowstorm in which some 300 people lost their lives[3]—is perhaps one of the most memorable of these; but almost every year similar winds blow over Texas and the Southern States; where a fall in the temperature from 70° or 80° to freezing

[1] On this viscosity, see a paper by Mr. Holman in *Phil. Mag.*, February 1877.

[2] *Naturalist in Nicaragua*, p. 299, *et seq.*

[3] *Times*, Feb. 8, 1873.

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point, almost within a few minutes, destroys vast numbers of cattle, and is occasionally dangerous, if not fatal, to men and women. In Cuba, or on the coast of Venezuela, the extension of these winds, warmed in passing over the sea, is only pleasantly cool; but in South America, a similar cold wind, from the sea beyond Cape Horn, or from the snow-clad passes of the Andes, is often felt in Paraguay, and reaches, not unfrequently, as far north as the valley of the Amazon; where almost every year there comes a cold spell in May or June or July, which lasts sometimes for three weeks, and kills not only the nearly naked Indians, or the beasts in the forest, but even the fishes in the river.[1]

These are some at least of the marked instances of these cold winds or cold spells. Others might be easily adduced; and amongst them that regular recurrence of cold weather in England every April or May, which makes us wonder, and more and more each year as we get older, what our forefathers meant when they talked of the merry month of May, or of the delights of going a-Maying.

But besides these principal causes of marked geographical or local differences of temperature, there is another which affects rather the regularity of temperature from hour to hour, from day to night, from summer to winter. This is the humidity of the air. It has been

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[1] Wallace's *Amazon and Rio Negro*, p. 431; Bates's *Naturalist on the*

proved, both experimentally and by geographical observation, that the heat of the earth radiates with much greater ease through dry air than through moist. If the air is moist, the heat which passes through it from the sun is almost altogether shut in and cannot escape: if clouds afterwards cover the face of the sky the effect is intensified; but if, on the contrary, there are no clouds, if the sky is clear and the air dry, then radiation from the surface of the earth goes on freely, the heat passes away into space, and the ground and the air near it become sometimes intensely cold as soon as the sun sinks below the horizon.

This change from a hot day to a cold night is often well marked in England or the neighbouring countries; in May it is frequently most deadly to the young vegetation, or to the buds and blossoms of the fruit-trees. A night or two of such frost brings loss or ruin to the wine-growers of the south of France, who try—and I am told with good success—to prevent the excessive chilling by lighting fires of damp litter on the weather side of the vineyard, so that the smoke, as a cloud, may hang over the tender vines. Our English gardeners get a similar protection for their plants by spreading over them a net, borne up off the ground by short stakes; and this—almost ridiculous as it seems—is sufficient to check the radiation.

But this alternation from heat to cold is still more strongly marked in the great deserts of Africa or Asia, where the air is so dry that the radiation is extremely rapid, and the differences of temperature are excessive.

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This is the peculiar character of what are commonly known as continental climates, in contradistinction to insular: there is but little vapour in the air, consequently a scanty rainfall, no heat of condensation set free, and radiation unchecked. It is in this way that countries in the east of Europe, and in Asia, which have a burning heat in summer, experience in winter a climate that may fairly be called Arctic. The plains of Lombardy, where in summer rice comes to maturity, have in winter a temperature as low as that of the north of Scotland. The history of our own time has made us familiar with the accounts of Crimean heat and Crimean cold. In Bulgaria and Asia Minor there are the same extremes. With the intense winter cold of Khiva, in the latitude of Naples or Lisbon, the story of Captain Burnaby's celebrated "Ride" has made every one well acquainted, and that in a country which in summer is almost impassable from the heat. We have all read of the sufferings of the Russian troops in the summer campaign of 1873, and how, almost by accident, they were saved from utter destruction: on a former occasion, 1839-40, they had attempted a winter campaign in the same country, but were driven back with great loss by the cold, which on several occasions passed below the freezing-point of mercury, and once fell to 46° below zero. This is equal to the rigour of Siberia, and Siberian cold is proverbial, although Irkutsk is in the same latitude as Cambridge or Northampton, and Yakutsk is little to the north of the Shetland Islands.

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It is thus very evident that a mere knowledge of the mean temperature of a place gives little or no idea of its climate, or of the forms of life—animal or vegetable—for which it is fitted. The mean temperature for the year is about the same in the Hebrides and on the north shore of the Caspian, or of the Sea of Aral; but there are perhaps no places, between which a comparison can be made at all, where the climate is so different. The intense cold of the eastern winter is immediately followed by a summer of great brilliancy and warmth: there is neither spring nor autumn, unless the few days of change may be considered so: corn is sown, springs up, ears, and ripens within a few weeks; and choice vines, apricots, peaches, or mulberries, with a very moderate amount of care, bear fruit abundantly; whilst in the Hebrides, where snow seldom lies for twenty-four hours, and thick ice is almost unknown, the summer is so little better than the winter, that corn ripens only in exceptional years, and fruit of any kind is an impossibility.

The climate of the countries bordering on and near to the Straits of Magellan is, by the general consent of all who have personal experience of it, the most disagreeable on the face of the earth: "It is so disagreeable," says Admiral Fitzroy, "that the country is almost uninhabitable. Clouds, wind, and rain are continual in their annoyance. Perhaps there are not ten days in the year on which rain does not fall, and not thirty on which the wind does not blow strongly; yet the air is mild, and the temperature surprisingly uniform through-

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out the year." It is, in fact, uniformly low: it seldom falls much below freezing point, but seldom also rises much above it. Extremes of cold are unknown; and even with the thermometer at freezing point, the screen of vapour mitigates the rigour of the climate. It is thus that the vegetable and animal life of Tierra del Fuego and of the mainland of Western Patagonia exists under such apparently anomalous conditions: dense forests on the mountain-slopes stretch upwards to the line of perpetual snow; ferns, of genera closely allied to, if not identical with, some of tropical haunts, grow freely; large woody-stemmed trees of fuchsia or veronica may be seen, in full flower, within a very short distance of the snow-line; flocks of parrots feed on the seeds of Winter's Bark, an evergreen shrub, which they perhaps mistake for its Brazilian relatives; and humming birds—despising the rain, snow, and sleet—go about merrily, sipping the sweets of the fuchsias, as far south as the latitude of 53° or 53½°.[1] Farther north, the contrasts are almost more apparent; and in the island of Chiloe, in latitude 42°, where the inhabitants are frequently compelled to cut their corn before it is ready, and bring it into the houses to ripen, the traveller, wandering into the forests, might almost fancy himself in the Brazils. "Stately trees, of many kinds, with smooth and highly-coloured barks, are loaded by parasitical plants of the monocotyledonous structure; large and elegant ferns are numerous; and arborescent grasses

of 30 or 40 feet above the ground."[1] In Tasmania, in New Zealand, similar anomalies present themselves: tree ferns, which in the northern hemisphere are not found beyond the tropic, grow in New Zealand, as far south as the latitude of 45°; and others seem to form a connecting link between the very different climates of Java and Van Diemen's Land.

Now these climatic paradoxes may perhaps be, to some extent at least, explained by the remarkable power of living things to accommodate themselves to circumstances; but the more important lesson which they convey seems to be that the distribution of animal or vegetable life depends in many cases not so much on the mean temperature as on the extremes; and that, while marked extremes, with a wide range and a high summer temperature, are favourable to some species; to others, more tender, less capable of enduring cold, a small range and extremes of no great compass are more suitable. Grape vines would no more bear fruit in Fuegia than would humming birds continue to chirp on the banks of the Volga, though the mean temperature at Port Famine and at Astrakhan is about the same.

Hence, then, in the study of climate, it is necessary to observe not only the highest and the lowest temperatures, but the mean. As much more knowledge as we can get is always desirable, but this much is indispensable, and calls for careful and accurate observation. Our own feelings tell us little or nothing. It is

[1] Darwin, *Journal of a Naturalist*, p. 271.

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not only that sudden changes are deceptive. There are persons so happily constituted that a cold winter's day seems to them mild and pleasant; there are others who would complain of cold on a broiling day in July. Other climatic factors also, as well as air temperature, affect our sensations: the effects of moisture, dryness, calm, or wind, are frequently indistinguishable from those of changes of temperature; or rather, as far as we are personally concerned, they are absolutely the same. Every one knows how wine may be cooled by wrapping the bottle up in wet flannel and hanging it in a draught; the hotter the day, the cooler will often be the wine. What do you think would be the effect of treating a man or boy in that way? It would probably kill him. Any of you who have been in India will remember very well the unpleasant consequences of the punkah-coolie going to sleep; and yet so far as it produces any change at all in the temperature, the real effect of the punkah, by churning up the air, must be to warm it. I have myself a very lively recollection of an evening at Hong Kong, when everybody was gasping for breath, declaring that it was hotter than man had ever before known it. To corroborate his words, some one went to look at the thermometer; it stood at 85°. I have often felt the heat less oppressive with the thermometer 15° or 20° higher. Again, the recorded experiences of numberless Arctic travellers show that Arctic cold may often be pleasant enough. This is one of the latest, as given by Dr. Moss, in that gor-

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"In comfortable winter-quarters, and with plenty of dry clothing, we found the extremest cold rather curious and interesting than painful or dangerous. An icy tub, on an English winter morning, feels colder to the skin than the calm Arctic air. Cold alone never interrupted daily exercise; it was possible to walk for two or three hours over our snow-clad hills, in a temperature of 100° below freezing, without getting a single frost-bite, or perceptibly lowering the temperature of the body. It is possible even to perspire if one works hard enough. Our experience led us to think that men, thoroughly prepared, might safely encounter far lower temperatures. Many a time, as we sat round the stove on the main deck, discussing the events of the day and the state of the weather, the relative merits of Arctic cold and tropical heat were warmly canvassed. Several of both our officers and men had lately returned from the Ashantee campaign, and they could speak with authority. There was one thing clear, one could sometimes get warm in the Arctic, but never get cool on the Coast."[1]

Such experiences as these are simple illustrations of what I mean when I say that, in order to institute a strict comparison between temperatures, whether in the same place at different times, or in different places, and under many different circumstances, exact measurement and observation are necessary. Without these, any record of climate is capricious and uncertain.

Now, I may assume that every one here knows

[1] *Shores of the Polar Sea*, p. 47.

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that temperature is observed and measured by means of an instrument called a thermometer, and knows also, in a general way, what a thermometer is. But there are thermometers and thermometers; and between the rough instrument of every-day life, such as is hung up in a bath-room or a hot-house, and the delicate instrument used for accurate observations, there is a very wide difference, the extent of which may be roughly, though very inadequately, estimated by the difference of price: a common bath-room thermometer may be bought for a shilling or eighteenpence; a good standard thermometer, simple as it seems, and without ornament of any kind, but solely on account of the care and skill expended on ensuring its accuracy, will cost from two to three pounds.

But given the thermometer, the important question is what to do with it? How or when is it to be observed? Where is it to be put? For of course every one knows that the thermometer has different readings at different times of the day; and that its reading even at any one time depends very much on where it is placed. But though every one knows this, every one does not act accordingly; and I have seen thermometers, which were supposed to give their owner some idea of the temperature, fixed in very remarkable places. The drawing-room mantelpiece, with or without a fire underneath it, is by no means an uncommon place to see a thermometer; I know, at the present time, of one fixed outside a dining-room window fronting the south-east, where it receives the direct heat of the sun

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for several hours every forenoon, and the heat absorbed by the neighbouring bricks for the rest of the day. And putting such extreme instances on one side, a great many people are apt to forget the necessity of care in placing a thermometer so as to allow it to register the temperature of the atmosphere at the time being.

It is now definitely concluded that the true temperature of the atmosphere is its temperature in the shade: the heat of the sun's rays is a different thing altogether. Now shade, to be perfect, ought to shelter the thermometer from all disturbing influences; not only from the direct heat of the sun, but from the radiation of bodies warmed by the sun, or from radiation to colder bodies or into space, from rain, and the consequent chilling by evaporation; the temperature which we want to record is that of the air; and, as far as possible, all the surroundings of the thermometer should have that same temperature.

There are, however, many practical difficulties in the way of obtaining that ideal condition; and many different ways of overcoming them have been tried, but none perhaps with perfect, or at least with undoubted, success. Many different stands for thermometers have been devised; and some of them no doubt answer fairly well; but theoretical objections may be raised to all. Those that, whilst giving effective shelter from the sun, are more or less freely open, are thought to permit radiation to or from distant bodies—houses, walls, or even the sky. Those that are closed from this

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source of disturbance are, on the other hand, thought to be too confined, and not to allow free access of air.

At the Royal Observatory at Greenwich the stand which is in use is a modification of what is known as the Glaisher: it may be described as simply a pent-house of wood, fixed on a vertical post, round which it may be turned, so as always to face away from the sun. The double-boarded roof, as well as a vertical partition descending from the ridge, certainly screens the thermometer from the sun's rays, and to some extent from the sky; but this last shelter is apparently imperfect: it looks as if rain might occasionally strike inside; and radiation to the surrounding objects is unchecked. Still these disturbances seem to be slight; and the Glaisher, or some similar stand, has a wide circle of approval.

I think, however, that I am right in saying that the general feeling of both English and Scotch meteorologists is, that open stands are not the best; that, even with their admitted imperfections, closed stands with louvre-boarded sides are preferable. The stand now adopted at all the observing stations of our Society, as well as at those of the Scottish Meteorological Society, is that known as the Stevenson, a box with double sides, something like a small meat-safe. The real objection to the Stevenson stand is that it is too small. I believe that if it was twice as big, in every way, it would be a very great deal better. But as it is, it is now the one in most general use in this country, and has the great

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parable with each other; it may perhaps not be the best stand that could be devised, but better even than Utopian excellence is absolute uniformity of pattern.

A curious and interesting way of getting over the difficulty which we all recognise as involved in the question of thermometer stands, has been repeatedly tried, with results which tend to give confidence in its correctness. A thermometer is tied to the end of a string some 2 or 3 feet long, and swung freely round and round. This is what has been called by the French, from whom we derive the idea, the *thermomètre fronde*, the "sling thermometer." At first sight, it is perhaps difficult to believe that the true temperature of the air is to be obtained in this way; but in point of fact, except in the full glare of the sun—and it is even doubtful whether such an exception is needed—a thermometer so slung is found to read within 0·5° of one sheltered in a Stevenson stand; for occasional purposes it may be fairly trusted, and will certainly give travellers a better idea of air temperature than such impromptu observations as they are sometimes in the habit of recording.

A point of importance almost equal to that of position or shelter, is the time at which the thermometer should be observed. The readings of most interest are the highest and lowest in the twenty-four hours; but special thermometers are made to record these automatically. I will not attempt to describe the several ways in which this record is made. The one now most favoured by English

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observers for marking the maximum or highest reading is, I think, that which was invented nearly fifty years ago by the late Professor Phillips: about an inch of the upper part of the mercurial column is separated from the main body by a small bubble of air; this, as the temperature rises, is pushed up; when it falls, is left behind; stranded, as it were, at high-water mark. To mark the minimum has been found more difficult; and though many ingenious methods have been proposed, I do not know that any can be considered quite satisfactory. The one to which there are fewest objections is perhaps that known as Rutherford's minimum thermometer, in which the temperature is shown by a column, not of mercury, but of spirit; this, on contracting, drags with it a small light index, which it flows past on expanding again. Another interesting form of thermometer, now nearly a hundred years old, and known, after its inventor, as Six's, records both the maximum and minimum. The cost and complex arrangement of this thermometer has prevented it from being generally used for observations of air temperatures; but it has rendered valuable service in the deep sea; and since the improvements suggested about ten years ago by Dr. Miller, and carried out under his directions by Mr. Casella, it has become recognised as the only instrument to be depended on when subjected to great pressure. This thermometer known commonly as the Miller-Casella, was used on board the "Challenger."

But more recently still, Messrs. Negretti and Zambra have invented a thermometer for taking deep

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sea temperatures, which, if it does not supersede the Miller-Casella, will at least probably be found a useful auxiliary to it; for whilst the Miller-Casella registers only the lowest temperature met with, at whatever depth, this of Messrs. Negretti and Zambra registers the temperature at the bottom. The instrument is so ingenious, so new, and as yet so little known, that I think you will readily pardon me if I dwell for a minute or two on its construction.

The thermometer itself, like the well-known maximum thermometer invented by the same makers, has a small obstruction in the throat of the tube, near the bulb; this answers as a valve, past which the mercury readily flows as it expands; but past which, when the tube is horizontal, it cannot return. But differing from this, the deep-sea thermometer has a siphon-shaped tube, and is fixed in a case, so that whilst it is being lowered through the water the instrument remains vertical; but as soon as it begins to ascend, the upward motion brings the pressure of the water on the upper surface of a broad screw, which is thus made to revolve in the opposite direction, and by means of a small cog-wheel, to turn the thermometer completely round, thus pouring all the mercury above the stop into the other leg of the siphon-shaped tube, where it remains till it is read off. The instrument has not yet, I believe, been tried—or at least fully tried—at any considerable depth, so that it is impossible to say that it will certainly answer when under great pressure; but it seems probable that it will, and be a valuable auxiliary to, and

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check on, the older instrument, which, with all its merits, has some serious faults, and requires always very great care.

As an instrument for correctly observing air temperatures, this thermometer promises to be even more useful: it can be attached to some very rough clockwork, which will turn it over at any set time, just as an alarum will go off; and in this way a row of them may be turned over, one every hour, or one every two hours, and the temperature recorded twenty-four or twelve times a day, without further trouble to the observer than reading them off, all at the same time, resetting them, and winding up the clocks.

For, apart from the maxima and minima, we want to know also the mean temperature; and for this, with ordinary thermometers, we must determine when they should be observed, in order from a few readings to calculate a true mean; or, in every-day words, to strike a fair average. On this point there has been a very great difference of opinion. If the thermometer could be observed every hour, or every two hours, the sum of the 24 or 12 readings, divided by 24 or 12, would be accepted as a mean without dispute. But only in the largest observatories, with a regularly organised staff of observers, has this been possible. We are, for the most part, obliged to rest content with two or perhaps three observations. This being the case, it is a very important question when these two or three observations should be made. The convenience of the observer—generally a man with some business to attend to—must

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necessarily have great weight in the decision; and taking this into consideration, our Society, whilst insisting on uniformity for the sake of comparison, has resolved that at all its stations the observations are to be made at 9 A.M. and 9 P.M. These are not only the most convenient hours for the greater number of amateur observers, but they are the best of any two for giving a mean temperature. Different methods of obtaining a mean from them have been proposed. Thirty years ago Mr. Glaisher published a table of corrections, by which the mean observations at any hour might be turned into the mean for the day; and other similar corrections have since been proposed by the Smithsonian Institution. It is, however, more than doubtful whether any one set of corrections is applicable to observations at different stations, or even at the same station in different months; and the Society, recognising that half the sum of the mean readings at 9 A.M. and 9 P.M. is rather below the mean temperature, and half the sum of the mean maxima and minima is rather above it, now publishes these four readings for each day, and suggests that their sum, divided by four, will not differ more than 0°·5 from the true mean, and may—should it at any future time prove desirable—be corrected according to any method then established.[1]

[1] The general opinion of the Society may be gathered from a paper laid before it in March 1877 by Mr. Marriott, and from the discussion which followed (*Quarterly Journal of the Meteorological Society*, new series, vol. iii. p. 399 *et seq.*); but more certainly from the action of the Society in regard to its observing stations, as shown in the report on them in No. 27 of the *Journal*.

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Undoubtedly the best and truest means are to be got from the continuous record made by photographing the registering point of the mercurial column of the thermometer. This is either the top of the column, as at Greenwich, or a small air bubble interposed in a longer column, as at Kew and the other principal stations of the Meteorological Office; but in either case the mark of it is thrown, by a carefully-adjusted lamp, on a sensitive paper, wound round a cylinder or drum, which revolves by clock-work once in the twenty-four hours. To such a trace a scale is easily applied, which translates it into degrees at any wished-for hour; but its great advantage is, that by measuring the area cut off, the mean height of the trace, that is, the mean temperature, may be calculated without much difficulty, and with the greatest possible exactness.

Before leaving this subject I should like to bring to your notice one more instrument, which must as yet, perhaps, be considered as experimental, but which is one of the most ingenious, and may possibly prove one of the most useful of all registering thermometers. Its inventor, Mr. Stanley, has called it a chronothermometer, or thermometrical clock; it is, in fact, a clock, registering on its dial the beats of its pendulum pretty much as other clocks do; but its peculiarity is this, that the pendulum is a species of air thermometer, so fitted that the expansion or contraction of the air forces mercury out of a lower cistern into a higher, or allows the mercury to run back from the higher into the

continual change.[1] Any one who knows how to regulate an ordinary kitchen clock will at once see how the chronothermometer will go faster for an increase of temperature and slower for a decrease. The difficulty, of course, is in the adjustment. Mr. Stanley considers that he has overcome this; that the pendulum will beat faster or slower at a true rate, now corresponding to 50 beats a day for each degree of temperature, and that this may be advantageously made to correspond to 200. The instrument will thus record the mean temperature for any reasonable length of time—a day, a week, a month, or a year—with perfect accuracy, and without any calculation. If, in addition to this, it can be made, as I think it may be, by a continuous succession of electric contacts, to record each beat, and thus register not only the mean temperatures, but the temperature at every second of time, the scientific value of the instrument will be far beyond that of any ever yet made.

And now I must stop; not that I have exhausted the subject, but that I have already taxed your patience too long. I can scarcely doubt but that much of what I have said has sounded to many of you as a twice-told tale, though some indeed may have thrown the knowledge of it on one side and forgotten it. To such I may express a hope that the recalling of old memories has been not without pleasure. But to others, to whom what I have said may have come with the force of

[1] A detailed account of this instrument, and its fellow, the chronobarometer, will be found in the Society's *Journal* (new series), vol. iii. pp. 352-8.

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novelty, to those who have hitherto paid but little attention to this branch of science, whether it be called Geography or Meteorology, if I have been fortunate enough to awaken your interest, to have induced you to turn towards it for the future, I am so far your benefactor, that I have found for you another charm in life, that I have enlisted you as students in the service—I will not say of science, but of nature; that goddess ever fair, ever free; whose beauty age cannot wither, whose infinite variety custom cannot stale.

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LECTURE III.

THE BAROMETER AND ITS USES: WINDS AND STORMS.

In the first Lecture of this course Dr. Mann explained the Torricellian experiment, which was the origin of the barometer, so that it is not necessary to do so again. This experiment was invented by Torricelli in 1643. It was one of many experiments made by him with the object of investigating the cause of the rise of fluids into vacuous tubes, and this one in particular led to the discovery of the pressure of the atmosphere, due to the weight and elasticity of the air and vapours of which it is composed, and, moreover, gave an exact means of measuring that pressure. So productive of consequential results to science, so many highways and byeways of knowledge has it pioneered, that on this single experiment the imperishable fame of Torricelli reposes. He died at an early age; and though he achieved other successes in science, he and they would have been long since lost in oblivion but for this capital experiment. He even used a tube turned up at the open end, thus forming the first siphon barometer, with which instrument he detected variations in the atmospheric pressure. In endeavouring to show how the barometer has gradually been perfected into an instrument of precision, we start from this experiment as the

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initial instrument. Torricelli gave it no specific name; apparently he did not regard it as an instrument, but merely as a philosophical experiment, and for a long time it was known by no other name than Torricelli's experiment, or the experiment of the vacuum. Such, however, was the origin of the barometer, an instrument of the first importance in meteorology, which has led the way to the invention of the air-pump, the fire-engine, the hydraulic ram, which act by the elasticity and pressure of air, and of the steam-engine, which, as first constructed, was dependent on the pressure of the atmosphere for its efficiency. The barometer has also enabled scientific men to define the laws of fluid pressure, and the laws of relation between pressure, temperature, and volume of gases and vapours, so that in physics and chemistry it has been of essential service. It continues to be indispensable in the practice of these sciences, and in the working of the steam-engine. But with these matters we are not now concerned; our attention is entirely directed to the barometer as a meteorological instrument.

Disputations on the validity of Torricelli's discovery of the pressure of the atmosphere were happily confined to a short period, for they were at once and for ever cut short by Pascal, whose celebrity as much depends upon his crucial experiment with the barometer as Torricelli's on its invention. Pascal repeated the various experiments made by Torricelli, and satisfied himself of the pressure of the air, and the consequent rise of fluids into vacuous tubes. It then occurred to

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him that the Torricellian column must be affected by the quantity of air vertically above, and not at all by that below, its level; and, therefore, that its length must be proportionally diminished in elevated places. Accordingly, in 1647, he requested Mons. Perrier, his brother-in-law, to perform the Toricellian experiment on the summit of the Puy de Dôme, a mountain near his native town, Clermont. It was not until 19th September 1648 that Perrier could obtain sufficient leisure and a favourable opportunity to carry out the project. Early on that day, a memorable one in the history of meteorology, he assembled a distinguished party of ecclesiastics and seculars in Clermont, where, and in their presence, he several times performed the Torricellian experiment. The party then proceeded to the summit of the mountain, about 8 miles distant, where he also several times made the experiment, with this result, the column was 3·33 inches shorter than in the town. On the way down, at Font de l'Arbre, they found the column had an intermediate height. Thus he clearly proved that the air below the instrument had no effect upon it. Time would fail us to enter into particulars of this memorable expedition, or to describe the scrupulous care with which the experiments were carried out, and repeated again and again, so as to eliminate all sources of doubt. Suffice it to say, that if to-day we calculate from Perrier's data the heights of the stations where he observed, the results are surprisingly in accordance with the most recent measurements. Thus his observations give 3458 feet for the height of the Puy de

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Dôme above Clermont, and the actual height is now stated to be 3511 feet.

After giving brilliant proofs of scientific abilities of the first order, Pascal devoted himself entirely to a religious life, and died at the early age of thirty-eight. After his death his treatises on the "Equilibrium of Fluids," and on the "Weight of Air," were published by Perrier, in 1663. These contain the recital of the Puy de Dôme experiments, and show how the Torricellian column may be used to judge of the state of the weather. Pascal found that it has a range of 1·6 inch in France; that it is generally higher in winter than in summer. Readings of the Torricellian column were taken daily by Pascal at Paris, by Perrier at Clermont, by Chanut and Descartes at Stockholm, during the years 1649-50, at the same time, "in order to see if anything could be discovered by confronting them with one another." Pascal was thus the pioneer of the synchronous observations upon which modern storm-warnings depend.

Boyle, in 1665, observed the Torricellian column in relation to the weather, and gave it a scale and lettering. Hooke observed its ascent from the effect of augmented pressure at the bottom of coal-pits, and invented the wheel barometer, or weather-glass, which has been ever since a common household instrument. Professor G. Sinclair, of Glasgow, in 1668 and 1670 measured the height of some hills in Scotland. To the instrument, fitted up in a frame, he gave the name *baroscope*, or indicator of weight. The termination *scope* was afterwards changed to the more definite one *meter*, and the name

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barometer, now for the first time applied to Torricelli's invention, is intended to signify a measurer of the weight of the atmosphere. However, it must be acknowledged that its etymology has hardly this definiteness of meaning.

We have here specimens of the best modern forms of the barometer, Fortin's standard for observatories, Gay Lussac's standard for travellers, the Kew marine standard. Now, having glanced at these, let us revert to the original instrument. Before it could be got into these modern patterns, many things had to be found out and many improvements made. The original may be likened to a child of nature, these modern forms as children disciplined by science and adorned by art. Without going into details, the improvements which have led up to the perfect barometer may be mentioned. 1. The mercury must be pure. 2. Every trace of air or moisture must be driven out of the tube. This is accomplished by the process of heating to a high degree the tube while it is being filled, and was first practised by Cassini in 1740. 3. The tube ought to be accurately vertical. If not, a correction might be calculated and used, but in practice there is no difficulty in keeping the instrument vertical. 4. The level of the mercury in the cup varies with the rise and fall of the column; and, as the column is measured from this level, the relative capacities of the tube and cistern must be considered. The capacity error may be dealt with in four ways—(1) by a movable scale, the zero being always adjusted to the cistern level; (2) a movable base to the cistern—Fortin's invention, which allows the cistern level to be raised or lowered to

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the zero of a fixed scale; (3) a fixed cistern and a fixed scale, a correction being applied to the readings; (4) a fixed cistern, with a fixed scale, but the inches instead of being of the true length are contracted so as to read corrected for the alteration of level, as in the Kew plan. 5. Accuracy of measurement being all important in science, the scale must not only be accurately divided and adjusted, but it must be read off accurately, and to aid this a vernier is applied to it. 6. Mercury does not wet glass, but is repelled by it, the more so the narrower the tubes, hence the necessity for a correction due to capillarity. This was early noticed, and experimental determinations of its value for different sized tubes were made, but it cannot be said to be satisfactorily settled yet, as the correction is not a permanent one; it varies with the presence of the slightest trace of moisture, oxidation, or impurity in the mercury. 7. Temperature affects the length of the column and the scale, so must be corrected for. This was only satisfactorily accomplished when physicists had determined the dilatations of mercury, glass, metals, and woods. 8. The correction for temperature has practically settled the question of material suitable for barometer frames in favour of brass. Wood, which at first was used generally, is now only used for common instruments. 9. The construction of the tube has been modified to economise the mercury, and to maintain the vacuum. The latter, by the introduction of a funnel or pipette, the invention of Gay Lussac, its object being to arrest the ascent of air from the cistern. It is very useful in portable and marine barometers. 10.

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To render the barometer useful on board ship a portion of the tube must be contracted to a very fine bore. 11. When art, working upon science, has done its best, the barometer is still imperfect. The residual errors must be determined by comparison with a reputed standard, such as that at the Kew Observatory, and a certificate of corrections obtained. Barometers so verified may themselves be considered standard instruments, and it is with such instruments that meteorology as a science is mainly concerned. In this rapid way only have we time to trace the improvements which have made the barometer an instrument of precision. As regards observations from such instruments, we may say with Mr. Spottiswoode :—"As soon as a subject becomes a matter of strict measurement, or of numerical statement, so soon does it enter upon a mathematical phase. This phase may, or may not, be a prelude to another in which the laws of the subject are expressed in algebraical formulæ or represented by geometrical figures. . . . It is not so much elaborate calculations or abstruse processes which characterise this phase, as the principle of precision, of exactness, and of proportion."[1]

Fortin's barometer is the best standard for stations. Its cistern constitutes its peculiar feature. Its base is flexible, and its upper portion is a glass cylinder. The arrangement enables the observer to adjust the level of the mercury in the cistern to zero of the scale at every observation, so that the instrument has no capacity error. Loss of a little mercury from the cistern by oxidation or

[1] Address to the British Association 1878.

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leakage is of no consequence, and no alteration of the scale and frame is required for fitting a new tube.

The siphon barometer forms the best standard for travelling purposes. It can be made lighter than any other kind of barometer, and spare tubes filled with mercury can be carried to replace a breakage, as the tube, being read from both limbs, can be inserted in the frame without any definite adjustment to the scale. The mercury in the open limb gets oxidised and dirty, and a bubble of air is very likely to get into the lower portion of the column. It was to prevent the ascent of air into the vacuum that Gay Lussac invented the pipette. As the air can only find its way between the mercury and the glass, it ascends as far as the shoulder of the pipette, but can get no farther. The presence of an air bubble in the column must, however, cause it to read too high, when it occupies a portion of the contracted bore; care ought, therefore, to be taken to see that no air is there.

The barometer has been used at sea since the beginning of the eighteenth century; however, it was not till the year 1853 that a satisfactory standard marine barometer was contrived. This was the work of P. Adie, under the supervision of the Kew Observatory Committee. Its main features are a suitably contracted tube, having a pipette, a brass frame, a closed cistern, and a scale of contracted inches. To ensure the fitness of a barometer for use at sea as a standard meteorological instrument, it must be tested to ascertain, on the one hand, that it is not liable to "pumping" from the motion

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sluggish. It must also be compared in an air-tight chamber, throughout the range, 31 to 27 inches, with a standard barometer to obtain its errors. The corrections thus found include errors of graduation, capacity, and capillarity, are generally confined to the third decimal of an inch, and are frequently nil. Further, to adapt the instrument for use in ships of war, the covered up portion of the tube is packed with vulcanised indiarubber to protect it from vibrations and concussions as much as possible. A more perfect marine barometer could hardly be desired. Leakage from the cistern, or a new tube, vitiates the corrections, which must be re-determined. It is the most portable of all barometers.

The barometer has always been vaunted as a weather oracle, but it really has no pretences to such a dignity. It simply shows the statical pressure of the atmosphere above it. This pressure must change before there can be any variation in the barometer, supposing of course that it is kept in the same temperature. The air puts the mercury in motion, hence inertia and friction must cause the column to change after, not with, certainly not before, the air pressure varies. If it be admitted that every wind has its weather, then to observe the direction and the force of the wind is the first step to observe the weather. Now the wind is a dynamical condition of the air, one which we are accustomed to roughly estimate from our sensation, and it is very advantageous to have in addition an exact measure of the statical condition of the air at the same time, which the barometer gives us. We gauge then not only the horizontal movement of

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the air but its vertical mass as well, and with the two estimates we are better enabled to judge of proximate changes than with either alone. However, the practice has been, for the most part, to relate changes of wind and weather to the state of the barometer; and innumerable rules have been propounded to enable every one to become weather-wise by the aid of a barometer. Torricelli began them, Pascal and Perrier added to them, Halley, Patrick, Saul, and others extended them; something to do in this line was even left to Dalton, Jenyns, and Glaisher. I am free to say that I have not found a single rule, properly so called, among them. By rule, I mean a mode of arriving at certain results from determinate conditions. They are all mere connotations of the weather, with the heights and movements of the barometric column. They served a useful purpose so long as the barometer was used by every one as if there was no other barometer in the world, and will continue to do so. When the behaviour of barometers in different regions and countries came to be known, these connotations were thrown into a little confusion. A sort of elixir of them had been distilled and bottled up on the barometer scale, to satisfy the craving for condensation, for knowledge formulated—in short for science, which humanity manifests. I refer to the lettering on the scale, with which we are all familiar, which, however little objectionable in cities like London and Paris, when it got abroad among the hills and mountains, in the interior of continents, and away on the oceans, appeared sometimes grotesque, not to say absurd. In the main,

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it is progress alway, however hampered by mediocrity or imperfection of instruments and methods. The latest connotators introduced some reasoning, especially I will refer to that eminent meteorologist, James Glaisher. He says: The height of the barometric mercury is almost constantly changing; the average daily variations during the year, at Greenwich, are as follow:—

On 132 days the change is less than 0·1 inch.

„	123	„	it exceeds 0·1 and is less than 0·2.		
„	61	„	„	·2	„ ·3.
„	27	„	„	·3	„ ·4.
„	12	„	„	·4	„ ·5.
„	6	„	„	·5	„ ·6.
„	4	„	„	·6	„ 1·0.

and on one day in ten years the variation may amount to 1·25 inch. It is the changes which constitute the barometer an indicator of approaching weather. Whatever may be the height of the mercury, a sudden and rapid fall is a sure sign of foul weather, and the quicker and more sudden the sooner the change will be over. Mr. Glaisher has deduced the following relations between the velocity of the wind and the height of the barometer at the sea level:—Above 30 inches, 130 miles a day; about 30 inches, 160 miles; 30 to 29·5 inches, 210 miles; 29·5 to 29 inches, 260 miles; below 29 inches, 320 miles. These are not to be assumed as the normal relations between the varying weight of the atmosphere and the rates of horizontal motion of the air, but rather regarded as expositions of the fact that as the pressure decreases the motion of wind increases. "The barometer," says

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Mr. Glaisher, "may be almost neglected by the sailor when its readings range above the average, but when they descend below the average it is a warning which ought never to pass unheeded; and when the depression is sudden it is the sure and certain warning of the approach of storms." Hence the use of knowing in a general way the average height of the barometer—the geographical distribution of barometric pressure. Sir John Ross said: "In high southern latitudes, the barometer at 29 inches we learned to consider to indicate fine weather, although in England such a depression would be regarded very differently;" and Captain Maury said: "The seaman observes his barometer and finds it at 29·3 inches; now if he be in 56° N. he may look out for squalls, but if he be in 56° S. it is only the mean height of the barometer, or what 29·9 inches would be in 56° N."

The connotators were succeeded by the cyclonists, Franklin, Capper, Redfield, Reid, Thom, Piddington. These investigators of the laws of storms took barometers into their confidence, although they were very untrustworthy, being badly made, inaccurately measured, carelessly observed and reduced. Thus two barometers in the same ship read as in margin. Still their confidence was not misplaced. They discovered that the distribution of atmospheric pressure was symmetrical within the storm area; that while all great storms and tempests exhibit a wind blowing around a calm nucleus, this nucleus has the lowest barometer, and that the pressure increases all around to the very limit of the storm. This was a gigantic advance, and these important in-

Private.	Ship's.
30·00	30·25
29·00	29·00
28·50	28·35

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vestigations assumed the shape of laws of storms, about which big treatises were written, which became of inestimable service in the art of navigation. Dove seems to have endeavoured to reconcile the connotations with the laws of storms in his work on the gyratory theory of the winds. He succeeded in bringing a large number of connotations under the regime of reason, and to marshal them into some sort of order. Admiral Fitz-Roy, in the *Barometer Manual*, seems to have attempted to put the connotations into order on Dove's groundwork. It was intended for fishermen, boatmen, and pilots, not the knowing old salts who take leave of the land, certainly not. I have often wondered how much the poor fishermen must have puzzled over it.

In the earliest attempts at measuring heights by the barometer, the atmosphere was regarded as possessing the same density throughout its whole extent, which was found to be quite erroneous when the elevations were considerable. The next idea was, that the density of the air decreased as the altitude increased, but this was found not to suit the circumstances. In 1685 the famous Halley proved the theorem on which the calculation is now founded, and which establishes that, the heights being taken in arithmetical, the corresponding densities of the air follow a geometrical progression. Uniting practice with theory, Halley, in 1697, observed the barometer at the level of the sea and on the summit of Snowdon, and found it to stand respectively at 29·9 and 26·1 inches. From the known height of the mountain he was enabled to conclude that the air doubles its

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rarity for about three miles and a half of ascent. Much remained to be found out regarding the specific gravity of air and mercury, the effect of gravity and of temperature on both. The problem was improved or modified by Deluc, Horsely, Damen, Playfair, Roy, Schuckburg, and others; but its now generally accepted formula is due to the celebrated Laplace. Not to pursue this subject further, it may be shortly said that the barometer, or its substitute the aneroid, is now an indispensable instrument for contouring and levelling, especially where methodical surveys cannot be conducted, or where rapidity of results is desired.

As the elevation above the sea, or any other level, can be determined by barometrical observations, of course the problem may be reversed; the elevation of the barometer being known, its reading may be reduced to what it would have been at the sea-level; and this form of the problem is of the utmost importance in meteorology. It is impossible to compare the readings of barometers at different places until they are reduced to the sea-level. The laws of storms having been investigated from the data afforded by ships' logs, the barometers were all at the sea-level; when, however, the investigation was extended to the land, the barometric observations could not be usefully compared until reduced to the normal level. Now this important reduction is effected by means of Laplace's formula, and the consistent results which are every day and everywhere got from it, testify to the substantial accuracy of the vast amount of science which it encloses, as it were, in a casket.

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The ordinary observations of wind, the rough notations of the weather, together with readings from indifferent barometers, furnished by ships' log-books, sufficed for the researches which led to the discoveries of the laws of storms. More precise observations, and especially careful readings from accurate barometers, conducted to the grand generalisation that the so-called laws of storms are the laws of the winds everywhere and always. Thus scientific men have learned that no accurate and abiding progress can be expected from meteorological research, unless accurate instruments, precision in observation, and systematic methods are employed. Upon such a basis, Admiral FitzRoy, in 1860, was enabled, aided by the electric telegraph, to inaugurate a system of storm-warnings and weather-casts. Leverrier, indeed, had advocated the storm-warnings previously. FitzRoy was deeply imbued with the views of the cyclonists, and especially with the theory of Dove, which favoured the assumption that all winds were cyclonic, and in acting upon them practically he was perfectly right, but failing to make his views intelligible they were universally mistrusted by scientific men. In 1863 Galton came to his assistance, though he does not appear to have recognised it, for in *Meteorographica* the law of wind in relation to the distribution of atmospheric pressure is clearly expounded. The charts in this work, though they repel examination from the appearance they have to specimens of the *Pekin Gazette*, or to a Chinese spelling-book, are nevertheless clad in bright auroral colours in the memory of all who know them. They will become in

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time of fabulous value, for they were the earliest of weather maps; and it is somewhat significant that we are indebted to the same author for the main features of our daily weather charts, lithographed as we get them by post, or stereotyped as in the newspapers. The text to *Meteorographica* appeals to these charts of Western Europe as showing that the areas of barometric elevation and depression are enormous, and in their main features very regular, but ever changing their contours and their sections, whilst they also vary in the speed and direction of their motion of translation; that the areas of calms are invariably the centres of whirls of wind, or are situated between conflicting currents, and that there is one marked condition of temperature and cloud in connection with the wind, which is persistent, beautifully marked, and full of interest, namely, that a westerly wind is accompanied by an overcast sky and a warm temperature, while with an easterly wind the sky is pure, and the cold intense. Further, they testify to the existence, not only of cyclones, but of what the author terms anticyclones. To quote verbatim, "one universal fact is, that on a line being drawn from the locus of highest to the locus of lowest barometer, it will invariably be cut more or less at right angles by the wind, and especially that the wind will be found to strike the left side of the line, as drawn from the locus of highest barometer. In short, as by the ordinary well-known theory, the wind (in our hemisphere), when indraughted to an area of light ascending currents, whirls round in a contrary direction to the movements of the

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hand of a watch, so, conversely, when the wind disperses itself from a central area of dense, descending currents, or of heaped-up atmosphere, it whirls round in the same direction as the hand of a watch." Professor Ballot, of Utrecht, claims to have enunciated this general law of the winds before Galton, but he certainly proved it only for the small area of Holland. Subsequent research has now enabled meteorologists to define the general law of the winds all the world over, in this concise form :—The wind blows along the isobars or lines of equal barometric pressure, with a less pressure on the left of its course than on the right, in the northern hemisphere, and the converse in the southern.

So long as barometric observations were made at independent stations, and were not confronted with each other in respect to the same instant of time, all that could be deduced from them were hourly, daily, monthly, and annual averages. The majority of observers could only record observations once or twice daily with regularity, and these yield averages for the particular hours. It was soon discovered that the barometer had a diurnal variation, and an annual variation, so that, in order to discover the laws of these periodicities, a barometer constantly registering its height was required. Hence the invention of self-registering barometers, or barometers in mechanical connection with clockwork, of which there are several kinds, the best being the so-called barograph, perfected at the Kew Observatory, and used at the British Meteorological Observatories. It may be shortly described as a standard barometer.

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which is caused to photograph its fluctuations during day and night, clockwork carrying the sensitised paper round in front of the barometer. The daily barograms become records from which the values may be measured off for any required instants. The curve, reduced, may be published entire as in the *Quarterly Weather Reports;* which reduction itself is effected by a marvellous combination of scientific apparatus and skill. Means deduced for each hour of the day enable us to detect the diurnal range; the means of daily values for the months give the monthly values, which show the annual range; finally, the monthly values yield an annual mean.

As regards diurnal range, it exhibits generally two maxima and two minima, is greatest in amplitude and most regular in tropical countries, is lessened by increase of latitude and by elevation above the sea. Its epochs vary with localities and seasons. In Polar regions it almost vanishes. In tropical and temperate regions the times of maxima and minima are, roughly speaking, 9 A.M. and P.M., and 3 A.M. and P.M. In the tropics the phenomena of the barometric range are so constant that Humboldt remarked that the time of day might be inferred from them within seventeen minutes. If we remember that this is the amount of the equation of time in some months, their period becomes identical with the solar day, or the cause of the diurnal range of atmospheric pressure is to be sought for in the sun's action. Now solar heat raises and lowers every day the centre of gravity of the air over any given meridian; but this is a simple not a double period. The action of the sun,

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therefore, must be indirect, taking effect through an intermediate agent. That agent is probably the vapour of water always present in the air, ever varying, now invisible gas, again visible vapour, then gone as water. Aqueous vapour, visible or invisible, has a greater absorptive power for luminous heat than dry air. As the heat of day increases the vapour rises faster. The more it is diffused, the more of the solar rays it arrests, so that its tension goes on increasing till the hottest part of the day; after this it declines: it has, in fact, a maximum and a minimum, corresponding very closely with the diurnal curve of temperature. The atmosphere of dry air, on the contrary, has a minimum pressure about midday, when it is most expanded, and a maximum about midnight, when it is most contracted. The two periods of vapour tension and dry air acting together give the double period to the barometric column. This theory was broached by Dove, and supported by Sabine. It has been said that no scientific theory can be considered complete until it is so clear that it can be explained to the first man you meet in the street. Well, this theory certainly admits of sufficiently simple explanation, and any one might explain it to any man in the street to their mutual satisfaction. See here, for Toronto, the curve of vapour tension is very similar to a curve of diurnal temperature. It has a maximum about the hottest part of the day and a minimum about the coldest; the curve of the diurnal pressure of dry air is similar but reversed, the minimum occurring at the hottest part of the day, the maximum at the coldest. Combining the ordinates of the two curves,

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the result is the barometric curve, which exhibits a double period, two maxima and two minima, at about 10 A.M. and P.M., and 4 A.M. and P.M., respectively. But let us go to Ascension, and the case is altered. We still have a double period for the diurnal range of the barometer, but the vapour tension and the dry air pressure of which it is composed both exhibit a double period also. Such cases completely demolish the theory. The diurnal range of vapour tension does not always and everywhere conform to the simple oscillation. The capricious behaviour of vapour is, on consideration, quite inconsistent with such a theory; every cloud in the sky is a visible protest against it. A hypothesis then remains yet to be framed which shall account for the diurnal range of the barometer in all seasons and places.

In the suspended diagrams the meteorological curves for diurnal range are exhibited for Toronto and for the Island of Ascension, and the subjoined table contains the data from which they have been drawn. The curves of temperature are not shown; however, it will be readily understood that at Toronto not only does the curve of diurnal range of vapour tension follow the march of diurnal temperature, but that of the wind's direction does the same, and it would seem that the curve of wind force is of the same character, namely, attaining a maximum about the hottest part of the day and declining to a minimum about the coldest part of the night. At Ascension, although the vapour tension is so much greater than at Toronto, its variations are less, and its diurnal curve has two maxima and two minima. The

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abrupt turn of the curve of dry air pressure at 11 A.M. seems to point to error either in the observations or the reductions, as nature never acts in such a way. Then, as regards the wind's direction, it is so constant that it hardly shows any diurnal range. The force of the wind, however, exhibits unmistakably the same features of diurnal range as at Toronto.

Diurnal Range of the Barometer, Vapour Tension, Pressure of Dry Air, and of the Resultant of the Wind Observations.[1]

I. TORONTO, 1842, July 1st, to 1848, June 30th, six years.
II. ASCENSION, 1863 to 1865, two years.

	TORONTO.					ASCENSION.				
Hours.	Barometer.	Tension of Vapour.	Pressure of Dry Air.	Resultant Winds. Direction.	Force.	Barometer.	Tension of Vapour.	Pressure of Dry Air.	Resultant Winds. Direction.	Force.
A.M.	Inches.	Inch.	Inches.	N 40° W	Mls.	Inches.	Inch.	Inches.	S 52° E	Mls.
1	29·615	0·239	29·376	2·32		29·977	0·645	29·332		23·2
2	·615	·236	·380	40	2·33	·965	·642	·323	52	23·2
3	·615	·233	·382	39	2·25	·959	·641	·318	52	23·5
4	·616	·231	·385	39	2·15	·959	·641	·318	52	23·5
5	·621	·230	·391	38	2·11	·967	·642	·325	52	23·9
6	·631	·238	·393	40	2·23	·977	·644	·333	52	25·0
7	·639	·249	·390	42	2·22	·988	·645	·343	51	26·2
8	·646	·260	·386	48	2·22	30·000	·643	·357	51	28·0
9	·648	·270	·379	63	2·24	·008	·640	·368	51	29·1
10	·648	·277	·371	80	2·18	·006	·635	·371	51	29·4
11	·641	·283	·359	96	2·37	·002	·631	·371	51	29·7
N.	·629	·287	·342	103	2·61	29·983	·632	·351	51	29·7
P.M.										
1	·618	·288	·330	103	2·71	·966	·632	·334	49	30·8
2	·608	·288	·321	101	2·70	·950	·633	·317	49	31·2
3	·605	·286	·319	90	2·56	·940	·636	·304	49	30·7
4	·603	·284	·320	77	2·60	·938	·636	·302	49	30·5
5	·604	·282	·323	70	2·48	·944	·639	·305	49	29·1
6	·608	·275	·332	64	2·44	·955	·645	·310	50	28·3
7	·611	·266	·345	59	2·38	·970	·646	·324	50	26·3
8	·616	·259	·358	56	2·35	·985	·648	·337	51	26·2
9	·620	·254	·366	51	2·38	·996	·650	·346	52	25·8
10	·620	·248	·372	48	2·36	30·002	·649	·353	52	25·0
11	·620	·244	·376	46	2·28	·000	·648	·352	52	24·5
M.	·616	·243	·373	43	2·25	29·991	·648	·343	52	23·9
Mean.	·621	·260	·361	62	2·18	·976	·641	·335	51	26·7

[1] The Toronto winds are results of the years 1854-9.

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The annual range of the barometer is not so well defined as the diurnal, though no doubt it is dependent on the agency of aqueous vapour, both air and vapour being influenced by the sun's annual course. It is a curve of a single period, the maximum occurring in winter, the minimum in summer. The range of the barometer was first noticed by Dr. Beale in 1666, and its nature and causes have engaged the attention of philosophers ever since. Early in this century our knowledge of it in different parts of the globe was greatly increased by Humboldt, Ramond, Bravais, Kæmtz, Forbes, Sabine. Several hypotheses have been started to account for it. None have stood the test of experience; and the whole subject is still open to investigation. Unfortunately the data available in the form in which such an investigation requires it are very scanty. As it is generally admitted that vapour tension acts an important part in the phenomena, especial care ought to be given to measure it contemporaneously with the barometer, and to deal with it in a correlative manner. This, however, is too seldom done; the best observatories simply neglect this important branch of the inquiry. There is another circumstance which, during the last fifty years, has tended to diminish the ardour of researchers, of reducers, and of observers, and that is the mathematical machinery in which it has been the practice to grind up this subject. To such a state of mysticism have these long mathematical involutions and evolutions tended, that many meteorologists believe that their observations are actually improved by passing them through this mill.

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There can be no such virtue in any mathematical formula; though such a formula may indeed wrap up, as it were in a casket, the soul of the giant, here represented by a vast array of figures. I do not say that formulæ for cyclical phenomena are useless; but I advise caution in their employment. Only those who have worked at the mill know the friction, the labour, and the time involved in the process of passing statistical values into formulæ, and the reverse; while the preparation of the statistics is so much more needed for solving the problem:—What causes the periodic range of the barometer?

Let us now pass to the subject of geographical distribution of pressure. In the first place it may be remarked that, as regards the land, no progress could be made in our knowledge of this subject, until accurate barometers got into use, and a correct method of reducing their readings to sea-level was devised. These conditions being fulfilled, barometer observations made at different places may be compared in two ways. First, they must all be taken at the same instant of time: this is the synchronous method. Second, they may be taken regularly at each station at any given hour, and the monthly values may be deduced from them by applying a correction for diurnal range, if necessary; which is the statistical method. The synchronous method is followed in the preparation of daily weather reports now published by most governments. Our own official weather reports are from observations made at about forty stations on the coasts of the British Isles and adjacent seas, at 8 A.M. Greenwich time. The barometer observations having been re-

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duced to 32° and the sea-level, isobars are drawn from them. An isobar is a line passing through places which had at a definite epoch equal readings of the barometer.[1]

Thus, we see that the wind blows nearly along the isobars, with the atmospheric pressure always less on the left side of its course than on its right; and that the force of the wind is greater the nearer the isobars are together. If along a line at right-angles to an isobar a distance of 60 nautical miles be measured, and the difference of the barometer readings at the extremities of this line be taken, this is called a gradient. Hence, the greater the gradient the greater the force of the wind. Upon these official weather reports forecasts of impending weather were made in the first instance by Admiral FitzRoy. They were discontinued for some years, and have only recently been resumed in a more modest fashion. Let us try and understand how the barometer helps us to these forecasts. I don't for a moment wish to be understood to say that atmospheric pressure, as shown by the barometer, causes wind; I would decidedly put the case the other way. However, the indications of the barometer are much more accurate than mere estimates of the direction and force of wind, consequently the isobars become exponents of the wind. Given the isobars you can infer the winds, and *vice versâ*. Now, to fix our attention on something definite, if we could be sure that the isobars shown any morning would be the same the next morning, we would have at once a fore-

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[1] A chart of a cyclone, and a chart of an anticyclone were exhibited,

cast of the weather for twenty-four hours at least; and if we even knew how they would appear to-morrow morning, we should know how the wind must change in the interval, and thus have a forecast. This, you will perceive, can only be done by relying on the rate of change which is going on in the various barometers. Now I find that the mean duration of the rises and of the falls of the barometer in our latitudes is 2 days; about 75 per cent of them take longer than twenty-four hours; in exceptional long spells of similar winds and weather, they may take from 6 to 11 days. Hence, if you assume that the movement of the barometer will last for 11 days, you may make a forecast for that period, but the chances of being borne out by the actual weather will be very small. In short the chances for a tolerably accurate forecast for one day are not more than 75 in 100. At Greenwich, for the year 1876, the non-periodic fluctuations of the barometer were as follows:—

Month.	Mean Duration.				Longest Durations from			
	Min. to Max.		Max. to Min.		Min. to Max.		Max. to Min.	
	Days.	Hours.	Days.	Hours.	Days.	Hours.	Days.	Hours.
January . .	1	8	0	23	4	14	2	9
February . .	1	12	2	6	1	21	4	1
March . .	2	18	1	14	7	22	3	20
April . .	1	17	1	19	4	4	4	1
May . .	1	17	2	1	3	9	4	19
June . .	1	16	2	2	3	17	4	20
July . .	2	6	2	18	3	16	5	0
August . .	2	0	1	20	4	5	4	8
September .	1	12	2	19	3	11	9	20
October . .	1	14	1	20	3	8	4	3
November .	1	10	1	12	3	18	4	4
December .	2	4	2	10	5	21	5	16
Year . .	1	19	2	0	7	22	9	20

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In 1859 Maury wrote that one of the great practical questions of the age was a daily system of weather reports between Europe and America. We have not accomplished this yet. Recently, however, the *New York Herald* has been kindly sending us warnings of storms which are on their passage over the Atlantic. It is not yet satisfactorily shown that storms ever do actually traverse the Atlantic, from America to Europe. Nevertheless, it is worth while inquiring how our American friends manage this business. They are not very willing to show their hands, as the saying is. However, we may surmise how it is done. They have active agents who make extracts of the logs of all the steamers directly they arrive in New York, and by means of these extracts they can follow up all the storms which occur in our parallels. Thus it may often happen that information of storms is obtained by the *Herald* before they have had time to reach Western Europe. The *Herald* at once flashes the news by telegraph. We get the telegram surely and speedily, and the storm, if it does not vanish in due time, shortly afterward.

Monthly averages of atmospheric pressure have been calculated wherever barometrical observations have been made; but so long as they remain secluded in schedules in their own observatories, or in reports, their value is not known to its full extent. Buchan has undertaken the formidable task of bringing them together from every known source. Thus about four hundred places have yielded data, from which he has constructed monthly isobaric charts of the world, also a chart of

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their annual values. Like Atlas, he has taken the world in his arms, and girdled it with his isobaric lines. Only the general results of this stupendous work can here be mentioned. During December, January, and February, the atmospheric pressure is greater in the northern than in the southern hemisphere, and the converse during June, July, and August. Throughout the year it is lowest over the Antarctic Ocean, about 29 inches. In the hemisphere where winter reigns, the greatest pressure lies over the land; the larger the continent, the greater the pressure. In the hemisphere where summer reigns the low pressures are over the land, the high over the oceans. Some of the most remarkable areas of high and low pressures are the following :—

Period.	Position.	Pressure.
		Inches.
Dec., Jan., Feb.	Iceland . . .	29·4
	50° N. 170° W.	29·6
	50° N. 100° E.	30·4
	0° to 40° S. .	30·0
June, July, Aug.	40° N. 90° E. .	29·5
	30° N. 40° W.	30·2

During March, April, and May the distribution is more equable, with a tendency to decrease over India and Tropical Africa, and to increase over the southern hemisphere, especially over the land. During Septem-

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ber, October, and November the process of equalisation goes on in a contrary direction to that just described.

It had long been well known that in sailing from high latitudes towards the equator, the atmospheric pressure increases towards the tropics, and decreases thence to the equator. Buchan's investigation enables us to take a general view of the subject, and to inquire how the distribution of pressure is related to the systems of the trades, the monsoons, and the variable winds. To be brief, the isobars are related to the prevalent winds in accordance to the general law.

Consequent upon the development of the law of wind in relation to the distribution of atmospheric pressure, there have not been wanting attempts to express it in a general mathematical formula. The ablest mathematician who has dealt with the subject hitherto is Ferrel, in America. Everett in Ireland, Hann in Austria, Mohn in Norway, have followed in the footsteps of Ferrel, and Laughton, also, has written on the subject. They may be called expounders of the centrifugal theory of atmospheric circulation and distribution. They evidently believe with Newton that "The whole difficulty of philosophy seems to me to lie in investigating the forces of nature from the phenomena of motion, and in demonstrating that from these forces other phenomena will ensue . . . I would that all other natural phenomena might similarly be deduced from mechanical principles." The simplest form to which I can reduce Ferrel's final formula is this:

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$$G = \left(\frac{\cdot 524 \sin 1 + \frac{v}{r} \cos 1}{281 \cos 1}\right)^{v} \frac{P}{P_1}, \text{ where}$$

G = gradient in 60 geographical miles; l = latitude;
v = velocity of wind in miles per hour;
r = radius of curvature of the isobars;
P, P_1, = atmospheric pressure at the place of observation, and at the sea-level, respectively. When the place is at or near the sea-level $P = P_1$, and this factor disappears. The barometric gradient thus becomes a function, not only of the wind's velocity, but also of the inclination of the wind's direction to the isobars, the radius of curvature of the isobars, and of the latitude. The unfortunate feature of the whole matter is, that the theoretical values of G, furnished by the formula, are greatly in excess of the actual values. We have therefore yet to get a satisfactory formula. Meanwhile, without any refinement, it may be useful to have a very simple mode of interpreting gradients into wind force, as estimated by Beaufort's scale, or the converse, for the British Isles, which will be correct enough for all practical purposes of judging wind and weather at distant places, and proximate coming changes. Every hundredth of an inch of the barometric gradient in 60 miles may be assumed equivalent to a grade of Beaufort's scale of wind force; so that for ·01 the force is 1; ·07, 7; ·10, 10; and so on.

I am of opinion that no satisfactory expression for the barometric gradient will be obtained until meteorologists correct barometric observations for gravity. The

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mercurial barometer gives, indeed, the weight of the air as a scale balance anywhere, but it does not show the absolute statical pressure as a spring would do, as the aneroid would do if it were an instrument of precision. This is owing to gravity, which is greater at the poles than at the equator, greater at the sea-level than above it. For latitude and the vertical we might easily correct, but it seems to me that gravity cannot be the same over deep oceans, on shallow waters, on the coasts, and among islands even in the same latitude, while on a mountain, and in a balloon, it must be different at the same elevation, latitude being the same. Until we know something definite about this matter, we had perhaps better let the correction of the barometer for gravity alone entirely.

I said that the barometer was not a weather oracle, *per se*, and I equally affirm that the law of pressure, in relation to wind, affords no means of foretelling weather by itself. Fixing attention on areas of pressure, either high or low, merely; the weather changes which attend them are only to be forecast by such data as their extent and gradients always, and either (1) rate and direction of progress; (2) rate of veering of the wind; or (3) rate of barometric change. The latter two may be either for one place or for several distant places. The problem has thus a variety of phases, but generally it may be stated thus: Given the barometric pressure, wind and weather at a place, or region, at a definite instant, to estimate the changes during a succeeding interval, as a day or two days. Either the translation of the air,

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the veering of the wind, or the change of pressure, must be assumed as known for the interval, and all the rest results as a matter of course. We cannot here go into details. To assume translation, veering, and range, or even any two of them, is to assume too much; they involve each other. Care must also be exercised not to assume too great a rate; as, for instance, 135° for veering is an excessive amount, which leaves no room for failure in estimating successes at any one place, by such a criterion, though if pushed to its legitimate limit, it would accommodate a chaos of cyclones within a few degrees of latitude and longitude. As atmospheric pressure admits of being the most accurately measured of these data, rates of change are perhaps best reckoned upon its units.

As regards annual values of barometrical observations, no periodicity has yet been traced for them. They appear to me to afford the most precise data for investigating the sun-spot cycle as connected with weather. There are no *à priori* reasons known to me for supporting that theory, and I consider the great amount of labour expended in bolstering it up as very much misapplied, and the whole thing as a wild-goose chase, on such paths as the rainfall, the black-bulb thermometers, and auroræ. In last week's *Nature*, there is a paper on this very subject by Broun, which is well deserving of attentive study. Only I would remark that if it should be proved that the sun-spot maximum coincides with a barometric minimum, and the sun-spot minimum with a barometric maximum in India, there must be a

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region, or regions, where the law is reverse, otherwise we should have to account for an abstraction from our atmosphere in some years, and an accession to it in others.

Had time permitted, but I have too much taxed your patience already, I should have liked to have pointed out to you, and to have supported my opinions by those of other meteorologists, that statistical results tend to show that there is correlation between the meteorological elements considered either synoptically or statistically, that is to say both in relation to geographical distribution as well as in regard to a single station; and, therefore, it follows that the key to prediction is a foreknowledge of some one of them.

In thus tracing the barometer from its invention to its perfection, and recounting the information which it has afforded us, it seems to me that I have been trying to show, however imperfectly and inadequately, how knowledge of a certain kind has been accumulated, condensed, combined, and formulated. Now, wherever I find knowledge methodically reduced to order, I call it science. If you do the same, then we are agreed that we have been engaged with science to-night. And for my part I say not an infant science, but a growing science, much meriting public appreciation, for the health comfort and prosperity of all of us are more affected by it than by any other science, if we would but think about it.

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LECTURE IV.

CLOUDS AND WEATHER SIGNS.

THERE is no branch of meteorology in a more unsatisfactory condition than that on which I have to address you to-night. In the previous Lectures of the present course, we were introduced to subjects on which rapid progress has been made in the most recent times. In their ingenuity of mechanical contrivance, sensitiveness, and delicacy of adjustment, meteorological instruments are fast rising towards perfection; and although there is, and will be, wide room for discussion as to the best modes of obtaining information from our instruments, and still more as to the real meaning of the information we obtain, there is every prospect of a tolerably speedy consensus on these points. In the Lecture of last Thursday you entered on a subject on which progress of a still more interesting kind is being made. The law of storms is a topic which is stimulating enough, indeed, has often proved only too stimulating to the faculty of the scientific imagination. We feel that a complete theory of the movements of the atmosphere is attainable, that the problems which such a theory presents are not beyond the reach of human inquiry, and that we are actually making brisk, though somewhat hazardous, strides towards the solution of those

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problems. I am afraid you will meet with some disappointment when you proceed, as to-night, from the subjects which I have mentioned, to that with which we are now to be engaged, the subject of "Clouds and Weather Signs." We find ourselves suddenly introduced to a topic on which the amount of progress to be reported is comparatively slight and unsatisfactory. I am almost apprehensive that your reflections, as I proceed, will be somewhat similar to those we have experienced on the sight of the old-fashioned plough, almost as simple and unimproved as it was in the days of the Pharaohs, in the midst of the agricultural implements at the Paris Exhibition. Quite a rustic and antiquated air hangs about the subject of weather prognostics (one thinks of the word as spelt with a *k*) about signs derived from cloud-caps, whether day or night caps, from rising and falling mists, from morning and evening rainbows, and the resulting sensations of the shepherds. We seem going back to the days of Aratus and of Virgil; and, unfortunately, I am bound to confess that Aratus or Virgil would find themselves almost on a level with some meteorologists of the present day upon the subject of weather signs derived from cloud observations. Still I shall hope as we go on, not only to show you that the application of scientific principles throws interesting light on particular phenomena embraced in our subject, but also (and this will be my special endeavour) to indicate to you what appear to me to be the dim outlines of a future science of cloud-land. Of that science, I confess at the outset,

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I am profoundly ignorant, but, if I can awaken without being able to satisfy your curiosity, above all, if I can suscitate in others that faith in the ultimate achievements of this science which I entertain myself, our meeting to-night will not be without useful results.

It may clear our way if I mention at the outset an impediment to our progress in this branch of knowledge, arising from the nature of the subject-matter itself. Cloud observation is, in a very large measure, an incommunicable art. Keenness of sight, coupled with the habit of observing phenomena, are, of course, its first requisites. To these must be added a special interest in the particular class of objects, and the facilities of observation derived from a life spent in the open air, and in a favourable situation (I need hardly say that the proximity of a London fog is most unfavourable). Fishermen, sailors, etc., whose vocation keeps them much out of doors, and is also intimately connected with the changes of the weather, acquire, as individuals, a certain amount of proficiency in the art. Much of this is pure training of the eye, and cannot, by instruction, be made over to another. My own earliest recollections are those of looking at the clouds, and forming infantine speculations as to the causes of their forms and movements, and of being reprehended for exposing myself to all states of weather for this purpose. The tendency was inveterate, and to this day I have spent nearly a twelfth part of my waking existence in that occupation. I can now, when only the summit of a cloud, 40 miles away, is visible

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above the distant horizon, state with unfailing certainty whether or not rain is falling from the under surface of that cloud. Similarly, from the long habit of watching the motions of cirrus, I can detect at a glance a movement of these clouds, which most observers, after standing motionless to watch them for some minutes, fail to discern. And when I look at the moon on a cloudless night, I always *see* its motion through the sky. This is mere culture of the eye, similar to that which enables the Indian to track the footsteps of a wild beast among the fallen leaves, where we fail to see the slightest trace; or by which the Africander farmer of the Orange Free State, though not otherwise especially long-sighted, can distinguish a horse from an ox at the distance of 5 miles. On the other hand, I have met with people unaccustomed to the study of the clouds, whom I found to be absolutely devoid of the primary notions of perspective in looking at a cloudscape, actually regarding a solid cumulus as painted on the sky, and imagining a horizontal streak of cloud which stretches nearly from the zenith to the horizon as rising in an inclined column from the earth. These instances, both of precision and its opposite, are so extreme as to be almost grotesque. Inaccuracy, however, in cloud observation, especially in judging the distance, or in estimating the relative height, of clouds, is the rule and not the exception. For example, when cirrus or cirro-cumulus, at a great altitude, is moving in a rapid upper-current, while thin clouds nearer to the earth's surface are stationary or nearly so, I have found the greater

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number of people whom I have questioned on the subject to say, on looking at the sky, that the first-named cloud is the lower of the two strata. We find acute observers, like Forster, apparently falling into this mistake. Artists even, whom one would expect to make a special study of objects which are some of the grandest and most beautiful in nature, seem addicted, as a class (they must forgive me for saying it), to the habit of representing the impossible in their cloud portraits. I shall have, however, in a few moments again to touch upon the subject of painting in connection with this branch of meteorology. What I insist upon here is the necessity of individual experience in this particular study, and the impossibility of imparting the art of cloud observation.

Now you will naturally say, we are not desirous of acquiring the art; we want the *results* of the observations. It is the business of the specialist not to tell us of the difficulties of his work, but to give us some of its fruits. A lecturer on mineralogy must not take up the time of his audience by descanting on the labour of distinguishing between the varieties of minerals, but must point out the distinctions and the laws with which they are connected. Now, here lies our great difficulty to-night. I cannot exhibit to you specimens of the objects about which I am to speak. I cannot bring a cirrus or a cumulus cloud into this room, and then proceed to examine or point out its peculiarities. Not only so, but I cannot refer you to any collection of specimens, labelled and ticketed and ready for your

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examination elsewhere. Not only so, again, but I cannot well refer you by way of illustration to special types of clouds depicted in the well-known paintings of the best artists. Even of those painters who devote much labour to their cloud studies, by far the greater number employ these only to produce what we call "atmospheric effects;" and for this purpose the vaguest, least definite, and therefore least typical, cloud forms afford the materials most easy to handle. Neither can we blame the artist who reflects the mind or paints for the eye of the general public, to whom a cloud is a camel, weasel, or whale shaped mist, and nothing more. Again, I have not the cunning of the draughtsman's hand, and I cannot exhibit what I consider perfectly satisfactory drawings of the most distinctive varieties, though I shall show you presently, by aid of the lantern, reproductions of some portraits of a few special types of cloud. Further again, there does not exist in the minds of observers generally any very reliable classification at all. I have often found two fairly good observers looking at a cloud together to be divided as to the species to which it belonged. Lastly—and here I come to what I consider the most serious difficulty of all—the old nomenclature of cloud varieties is in itself unsatisfactory; and it would be premature to attempt to remodel it at present. Luke Howard was a very minute and accurate observer; but in his day the laws which regulate the movements of the atmosphere were not understood. The distinctions of cyclone and anticyclone, and the relation of wind and weather to the distribution of barometric pressures were

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totally unknown. Now I shall hope to show you that these are elements with which the forms as well as movements of the clouds are intimately connected: and a classification which takes no account of this connection, fails in a very important point. Again, the laws of atmospheric electricity were not so well understood in Howard's days as in our own, and the behaviour of the clouds is evidently controlled to a great extent by this agent. Here, indeed, we are still extremely ignorant; and until, by the use of captive balloons or other appliances, we have settled a number of hitherto unsolved questions about the electricity of the clouds, we must be content to wait, and not to adopt too hastily any new classification. The relation of the electrical states to evaporation and precipitation, on the one hand, and to the horizontal and vertical movements of the atmosphere, on the other, will one day be thoroughly understood. But until that day arrives, we can be neither too critical nor too cautious in our use of cloud classification.

Amid these embarrassments we must steer our way as well as we can. With the existing nomenclature of the clouds I shall to-night tamper as little as I can help; though I shall be forced every now and then to point out to you that in that nomenclature distinctions have been made where there are no natural differences, and what is at least as serious, that there are differences in nature where there are no distinctive appellations.

Cloud forms have been regarded as naturally divisible into three great genera, the cirrus, the cumulus, and the stratus. A dual division would, perhaps, be as simple

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and as true. There are first the clouds which tend to arrange themselves in a horizontal bed or layer, the components of which may be either fibrous and interlacing (which is commonly noticeable when the bed is at a great elevation), or more compactly welded together (which is more common when the bed is near the earth's surface), but whose vertical diameter is in any case very small as compared with its horizontal. And there are, secondly, the clouds of massive spherical or hemispherical shapes; often spherical or nearly so when in the higher regions of the atmosphere, but usually of the more hemispherical shape, and having a plane base, when in the inferior regions. These two great genera, however, are determined by form alone; and they exist, though with various modifications (such as that I have just mentioned), at all altitudes at which clouds are visible at all. Thus, at a vast height above the loftiest mountains and over the heads of the most adventurous aeronauts, the condensed vapour floats either in the thin reticulated sheet which produces our lunar or solar halos, or else in that flotilla of innumerable nubeculæ which gives such a tranquil beauty to many of our summer skies. And as we descend towards the surface of the earth we find these two primary varieties quite as distinctly noticeable. Even the fogs which rest upon the earth itself have sometimes a plane upper surface, like the white mist which at nightfall clothes the valleys with a silver sheet, sometimes a mountainous superstructure of towering cloud, swelling upwards in billowy folds. The first of these divisions comprises essentially the

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clouds of the night, and the second those of the day. Again, clouds of the first division are those of winter, those of the second, clouds of summer. But this rule applies with much fewer exceptions to the lower than it does to the higher portions of our atmosphere. Finally (but this rule again has many exceptions), clouds of the first division are more common over the sea than over the land; those of the second, more common over the land than over the sea. On the west coast of Norway, for example, I have often seen the mainland covered with massive piles of cumulus, while over the open sea were only a few streaks of linear cloud. Each little island had a little cumulus poised above it; a larger island a larger cumulus, and so on, the size of the cloud being almost exactly proportional to that of the land surface beneath it. It is even said that a reef when covered with shallow water often has its position marked by a solitary cloud of the cumulus form above it. Now it would be convenient to base our nomenclature of clouds on this natural division, and this has, to some extent, been commonly done. Unfortunately, as I think, Howard almost restricted the term stratus, or at least primarily applied it, to ground-fog, although he applied its compounds to clouds of all altitudes. In the present Lecture I shall make bold freely to use the word stratus, as well as its derivatives, of clouds of what I have called the first division. The term cumulus and its derivatives we will apply to those of the second.

The most valuable, however, of weather signs are obtained not so much from the shape of the clouds as

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from the directions from which clouds of different levels are observed to travel, and it is these weather signs, which, in the present state of our knowledge, can be most readily reduced to definite rules. From the use of synchronous weather maps there has sprung up in recent years a new science of the winds. With the principles of this science all the more reliable rules of weather forecasting are most intimately connected. We no longer think of judging of coming weather merely by the aspect of the sky and an examination of an individual barometer. We invariably refer—I do not say to the weather reports of a few hours previous, for we often have neither these nor any weather reports at all at hand—but we invariably refer to rules already deduced from the long study of weather maps. The man who ignores these rules had better, in my opinion, leave all attempts at weather forecasting alone. At best his weather lore will not rise much above that of the bees, which fly to the hive, often to their own detriment, whenever a dark cloud covers the sun. When to take, and when not to take, an umbrella is a question which involves at least an elementary knowledge of the relations of pressure and winds, of the general direction and interdependence of cyclone and anticyclone, in short, of the matter with which the meteorological services of this and other countries supply us. Now the movements of those clouds, which are at the greatest distance from the earth's surface, afford to the observer information of the highest value concerning the distribution and movement of the areas of barometric pressure existing

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at the time when he makes his observations. I am going to give you a few rules upon this subject. But we must first settle one point with regard to nomenclature. It is absolutely necessary that we should have some one term to designate unequivocally this highest class of clouds. We will employ then the term cirrus, and its compounds cirro-stratus and cirro-cumulus, but these terms, if our rules are to hold water at all, must be restricted to clouds of the greatest elevation. Owing to the fact already mentioned, that the term stratus has been applied to ground fog, observers have used its compound cirro-stratus of a great variety of clouds of all altitudes, and to the loose application of this word in meteorological reports and weather diaries is due, in great measure, the small amount of progress hitherto made in our knowledge of the upper currents. At one time the observer gives the name cirro-stratus to that filmy sheet of very elevated cloud which produces the halo; at another to streaks of linear cloud at not half that elevation; and finally, to make confusion worse confounded, the older observers tell us that even some of our fogs, I suppose frozen fogs, are "a species of cirro-strati." Further confusion, arising from the use of another term, which I must touch upon presently, hangs round the ordinary use of the word cirro-cumulus. In what I say to-night I employ the word cirrus only of those "curl clouds" or "mares' tails," which float at a great elevation (see Fig. 1). By cirro-stratus I mean the halo-producing sheet, which is formed by the interlacing fibres of more or less cirriform cloud. And finally,

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by cirro-cumulus, I mean those small white nubecules which float in the same level as the cirrus and cirro-stratus. I call these three descriptions of clouds generally, clouds of the cirrus class, and the currents which carry them I denominate simply upper currents.

Now the laws which govern the upper currents and their clouds are to some, though not to a very great extent, already understood. They are complex, and I should go beyond the sphere of this Lecture if I attempted to explain all that is known of them to you now, but I think I can tell you enough of them to be practically useful in forecasting probable changes of weather.

You all know that the winds at the earth's surface blow round any area of low barometer, which is also, generally speaking, an area of wet or showery weather, and that they blow in such a way as to have the place of lowest barometer considerably on the left (in our hemisphere) of their course. You have also heard that the depressions, or areas of low barometer, commonly travel from S.W. to N.E., or at least from some southerly or westerly to some northerly or easterly point. Likewise, that the majority of the centres of these depressions, around which the winds blow in cyclonic circulations, pass along on the N. or N.W. of this, and indeed of any part of the British Isles, while others travel directly over us, and some again leave us on *their* N.W. You also know that, besides these areas of low pressure, there are areas of high, anticyclones, as they are called, in which

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paratively speaking, stationary often for a considerable time, and their disposition seems to affect the movement or translation of the areas of low pressure, which commonly so travel as to have the anticyclone on the right of their course.

Now the old observers were quite right in telling us that we know a great deal about coming weather from the appearances and forms of the clouds. They comparatively neglected the prognostics to be obtained from the movements of those bodies. We must give our attention both to form and movement, but more especially to the latter, in judging of the disposition of the areas of high and low pressure.

If, when a light breeze from the south is blowing at the earth's surface, while clouds of various altitudes are passing overhead, you study with care the motion of these clouds, you will in general observe that their course makes a considerable angle with that of the surface wind, and that if your back is turned to the latter the clouds travel somewhat from your left hand to your right. Low scud will probably be seen to travel from S. by W.; stratus at a higher level from S.W., while the threads of cirrus, or fragments of cirro-cumulus, at a still higher level, move from a still more westerly point. Draw every day, when clouds of the cirrus type are visible, a dotted arrow indicating their motion on one of the daily weather charts, and you will find that, as a rule, the upper currents flow considerably across the isobars, and their motion is, on the whole, from the districts of low barometer towards those of high. You

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will find some singular exceptions to this rule, but of its general accuracy you will not be long in convincing yourselves. Now at the earth's surface the winds do not blow exactly parallel to the isobars, but in such a direction as to carry a portion of air from the districts in which the pressure of the atmosphere is high into those in which it is low; and it is therefore obvious that the air which thus finds its way into the regions of depression, there rises and escapes again above, eventually finding its way to the anticyclones, where it again descends towards the earth's surface. From an examination of instances of upper currents, it has been found that the upper current makes a mean angle of as much as 55° with the surface wind in our district of the globe. This angle is, however, far from uniform in the different portions of the cyclonic and anticyclonic areas. I will try to explain how the upper currents move under special but common circumstances, describing at the same time, as briefly as I can, the general aspect of the clouds prevailing in these circumstances.

There commonly exists in the front of an advancing barometric depression a great bank of the frozen moisture in the high regions of the atmosphere which we call cirro-stratus (see Diagram). Synchronous observations show that the edge of this bank is commonly curved; and that the curve is, roughly speaking, a parabola, the focus of which lies nearly in the line along which the centre of the depression is about to travel. We do not, however, commonly see this curve in looking at the cloud. What we do see are longitudinal threads, or filaments of thin

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cloud, at an altitude of between 25,000 and 40,000 feet above the earth, and so arranged as to be parallel to each other. Outlying streaks of this cloud, often from 20 to 100 miles in advance of the main pack, the pioneers of the coming army, can be examined without difficulty, and their general appearance is so well known that I need not describe it minutely to you. Suffice it to say that these threads of ice crystals terminate in most attenuated points, which are often curled more or less outwards or upwards, being apparently kept asunder by electrical repulsion, the whole thread acting as a horizontal conductor of electricity. As the actual bank comes over us the threads which compose it are seen to be more or less reticulated, forming a filmy sheet or canopy, the structure of which becomes less and less discernible. This is the form of cloud which produces our halos. Occasionally, indeed, even from the very first appearance of this sheet, we can scarcely discern any structure in it at all; the sky seems simply to become gradually overspread with a milky-looking film of whitish cloud matter. In this latter case we infer that the upper regions are especially humid, and that the crystals being less insulated consequently do not arrange themselves in definite threads.

In any case, as the bank comes more fully over our station, its under surface becomes lower, and is at the same time rendered indistinct by the formation of visible cloud matter in the lower regions of the atmosphere. The commencement of this stage usually coincides with that of the fall in the mercurial column; for the

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barometer is often either rising or stationary under the outlying threads already described. The rain-bringing wind now begins slowly to make itself felt at the earth's surface; the upper clouds cease to be visible at all, for the sky becomes totally covered by a composite mass of condensed vapour, and more or less precipitation at once sets in. When it clears again we shall have totally new conditions to examine. But while we are kept indoors, and have nothing particular to look at, let me go back and describe to you, as briefly and clearly as I can, what have been the movements of that upper current which has brought this cloudy canopy over our heads.

I have spoken of electricity as apparently determining to some extent the form of the cirrose filaments. Some writers have gone so far as to suppose that their motion through the sky is due to the same agent, raising the latter to the throne of "the cloud-compelling Zeus," who controls all the movements of the ice-mist. Observation, however, rejects the too ambitious claims of this potentate, and will soon satisfy any one that the movements of these clouds are controlled by winds, due to differences of pressure in the stratum where they float. Synchronous observations, made at different stations, carry us a great deal further, for they indicate the laws by which these upper currents are governed. I must not here attempt to describe to you those laws; but I must beg your attention while I describe some of the general rules which depend upon them, rules which he who wishes to be weather-wise will very frequently have to employ.

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I will suppose then, first, that depressions are travelling from S.W. to N.E. (which is with us their most common direction), an anticyclone lying to the S.E. of our district. First, let us imagine ourselves to be situated actually upon the line which is to be traversed by the centre of the disturbance. Cirrus threads will first appear upon the S.W. horizon, and parallel to[1] that horizon. Their motion can then be made out, though not very exactly, like that of any other moving body at a distance. When some of them have arrived at the zenith we shall find them to travel from some point between W.S.W. and W.N.W. (see Fig. 2). A little later, when an easterly wind has sprung up beneath, and when the cloud-bank is getting thick, we shall, if we can catch an opportunity of seeing the higher clouds, find that their current has "backed," that is to say, is now from a rather more southerly point. By and by, when the barometer has reached, or nearly reached, its minimum, if we have, as we probably shall have, an opportunity of going out again to witness the clearing of the sky, we shall find that this upper current has backed so much as to be then moving from a south-easterly point. The cirri

[1] Here, and presently, I employ the words "parallel to" a particular horizon, as expressing, briefly but intelligibly, parallel to the tangent of, or to a line which subtends, a particular arc of the circle of the visible horizon.

Apparently, i.e. as seen on the vault of the sky, the bands and banks of Cirrus are *arched*. Thus a band seen on the S.W. horizon is seen as most elevated in its middle part, viz. in the S.W., and lowest at its extremes. The observer must of course not confound this apparent curve with the real curve (shown in a cloud-map, or in the diagram), which I have previously stated to be rarely visible to the eye, in looking at the sky.

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will then be ranged in lines from S.E. to N.W. Their appearance will at the same time have greatly altered; they will have become much more massive, and their threads or tufts will commonly be seen to point in a more or less downward direction, indicating that a cold and drier atmosphere is setting in below (Fig. 3).

Now let us shift our position, or that of the advancing depression, and imagine that the latter, in this case also travelling from S.W. to N.E., is passing considerably to the N.W. side of our station; say, is passing along the N. of Scotland while we are in London. In this case the bank of cirro-stratus, or its out-lying threads, have first been visible on the W. or W.N.W. horizon, and parallel to that horizon, and the upper-current, when it can be observed, is found to travel from some north-westerly point. As the bank spreads over us, while the south-westerly wind springs up beneath, we observe the upper clouds to be less thick and watery looking than in the description I have given before. Cirro-cumulus often takes in this instance the place of cirro-stratus, which is probably an indication that no great conduction of electricity is going on aloft. The rain, if it reaches us at all, falls in spasmodic showers. And when the sky clears, we shall find that it does so far more gradually than is the case at stations nearer to the centre of the disturbance. Here, too, we shall find that the upper current has backed, but only to a W. or S.W. point, so that when the wind at the earth's surface has veered to W., clouds of every level over our heads will be found to move from nearly the same quarter.

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Once more I must trouble you to imagine our circumstances changed. A depression, still going in a north-eastward direction, is leaving us upon its left: is travelling, we will say, from the Bay of Biscay to Holland and Denmark, while we are in London. In this instance the cirro-stratus bank first shows itself on the S.S.W. horizon; and its motion, when it can be first determined, is from some point between W.S.W. and S. In this case, after the sky has thickened, and a north-easterly wind has freshened, with a falling glass, we very rarely get an opportunity of seeing the upper clouds at all: but when we do, at the time that the centre of the disturbance is nearest to us, we usually observe the upper current to have backed so as to come from S.E. The rain, in this instance, if it extends so far N. as our station, is cold, thick, and continuous. As it ceases the clouds remain for a little while low and dreary; the clearing of the sky is very gradual, and when the wind is gone round to N. and the barometer is rising, we commonly see that the main vapour plane has greatly descended, and that in lieu of the cirrus, cumulus, and shower-clouds which are being experienced in the far south, we have irregular but level stratus occupying the middle or rather lower beds of the atmosphere.

We must shift our position, please, once more, and suppose ourselves to be altogether in the rear of a disturbance, the central part of which has passed fairly off to the N.E. My task of description is here comparatively easy. The sky is either clear or contains fragmentary cumulus, and perhaps a few local shower-clouds. Such

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upper clouds as are seen are here commonly either masses or threads of somewhat curly cirrus; if threads they stretch from N.W. to S.E., and their motion is in any case nearly from that direction, and thus coincides or nearly so with the line of the isobars, and with the winds at the earth's surface. It is a very rare thing to experience a N.W. wind (except immediately after it has veered to that point), which does not extend to the highest regions of the cloud-bearing atmosphere.

Now you are probably aware that when depressions are passing over or near us, the general distribution of high and low barometer is not always such as I have been describing in the last ten minutes. A great anticyclone may be lying to our east, and depressions may be for some time travelling northwards; or, again, it may lie on our west, and depressions may be going south-eastward. You may be afraid that I am going to give a new set of rules for these conditions as lengthy as those in which I have already indulged. Fortunately for you I need do nothing of the kind. We have only got, in the first instance, to back, if I may be allowed the expression, all the words that I have used, S.W., N.W., etc., as much as four points, *i.e.* to S., W., etc., or, as I now do, to alter the position of our diagram, and the rules which I have already given will still be true. In the latter instance, namely, if the depressions are going S.E., we must veer our words as much as eight points, or shift our diagram, as I now do, and our rules will be as useful as before. I shall give one or two practical illustrations of what I mean. In weather in which we know, from the

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previous changes of wind, and, better still, from our study of the daily maps, that the depressions, or areas of rainy weather, are travelling from S. to N., the appearance of a thick bank of cirro-stratus in the S.E., moving from some point between S.W. and S. after an interval of fine weather, is often an indication of coming rain, probably heavy, and accompanied by a muggy N.E. wind. On the other hand, if, under the same circumstances, the first threads of cirrus or cirro-stratus are observed in the W., but are found to travel from the S.W., the rainfall is not likely to reach our station, at least in more than one or two passing showers.

Again, let the weather be such as we frequently have in spring, and occasionally in autumn and winter, winds backing and veering between W.S.W. and N., and the weather maps showing us that areas of bad weather are travelling from the Scottish coasts towards Holland and Denmark. Let a fine day be succeeded by a watery bank of cirro-stratus in the N.W., travelling from the N. or N.N.E.; bad weather is to be expected; a blustering westerly wind accompanied by composite cloud-bank will probably veer to a cold N. or N.E. gale, a hazardous time for the shipping on our N.E. coast. On the other hand, under the same circumstances, let the cirrus appear first in the N.N.E, and travel from a northerly point, we are not then likely to experience more than a few slight showers of sleet or snow, with only a moderate backing and veering of the wind.

I must not dwell longer on the motions of the cirrus clouds round our depressions. I hope that what I have

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said has tended to show you that the whole subject is one of great importance in making forecasts of the weather, and in judging of the probabilities of storms; and I shall be glad indeed if I have induced any of you to enter upon this class of observations as a study. You will have, in this case, many difficulties to get over, especially those to which I have already alluded, arising from the labour of training the eyes, but I can assure you that the pleasure and interest of the study, as well as its practical utility, will be the ample reward of perseverance.

I have already several times spoken of local showers, and must have seemed to pass them over as of little account. Now a temporary shower is often quite as important a matter, to the agriculturist, for example, or to the pleasure-seeker, as a steady downfall of rain; just as a squall is often a more formidable matter to a sailor than a gale. Moreover, to judge of the chances of the passing shower or squall, is a more difficult task, to ordinary observers, than to prognosticate more continuous bad weather. Here, again, we must first allude to a matter of phraseology. Howard, the cloud classifier and cloud classic, called every form of cloud from which rain falls by the name nimbus. In the Latin definition which he gives of this name, he does appear to indicate a twofold division of nimbi or rain clouds; but neither he nor his successors have told us very much about this division. I have shown you that the symptoms of the extensive rainfalls become first apparent, as a general rule, in the higher regions of our atmosphere; the cloud-

posite cloud at a lower level. The formation of passing showers is commonly the converse of this process. I must briefly describe that formation, familiar as it is to most observers. Almost every one must have watched the formation of a cumulus cloud, probably in the earlier hours of a showery day. Loose shreds of irregular cloud matter begin to appear here and there under the bright blue. They are at first near the earth's surface, commonly in what has been the vapour plane of some stratus in the preceding night. Gradually, as rapid evaporation goes on under the increasing power of the sun's rays, the rising vapour forces upward the particles above it, which are condensed by the cold of the higher regions into more and more mountainous masses. The under surface remains level, reposing on the vapour plane, that is, precisely at that altitude above the earth at which water passes from the gaseous state to that of mist. Below the cumulus the vapour is rising, but in the invisible state, like the steam out of the funnel of a locomotive, which is often invisible until it has risen a foot or more above the aperture. Looking aloft, we see the general shape of the cumulus to be, as I have described it before, that of a hemisphere, or possibly of a cone. It is not, however, smooth, but still resembles the steam-cloud of the locomotive in exhibiting rounded protuberances. If you look at these you often see them continually tumbling back into the main body of the cloud, which yet continues to swell gradually upwards and outwards. That the older meteorologists were right in attributing this process principally to electric disturbance I, for my part, cannot doubt. The

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cloud is now an insulated body more or less highly charged. It repels the opposite electricity from the particles in its neighbourhood, and attracts them to itself, and an invisible rain of such particles is perpetually pouring probably upon all parts of its surface, the general charge of the cloud being retained partly by reason of its spherical surface. While we have been watching our cloud many others of similar structure have formed in other parts of the heaven, and our attention is attracted towards the horizon by the roll of the first distant thunder clap. We see in the quarter from which it has proceeded a cumulus or body of cumuli, the upper surface of which has put on quite a different appearance. It is spreading outwards and upwards in very thin cirrus-like filaments (Fig. 4). It has, in fact, risen to such a height as to approach a stratum of gas intensely electrified, and with an electricity opposite to its own, and it is disposing the ice prisms in innumerable threads or feelers, spreading their attenuated points through the lofty regions of highly rarefied air. We look again at the cumulus which we have watched before. Its glowing summit is undergoing a similar metamorphosis, becoming softer and more downy than the lower portions of the cloud. Exactly at the same time that this change is taking place we notice the atmosphere beneath our cloud to begin to be dimmed by the falling rain. The neutralisation of the electricities aloft has permitted the particles of water, hitherto kept

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seen of the melting cloud save a certain amount of cirrus disposed above, and some loose flecks of scud, or of soft cumulus beneath.

This is the first formation of the typical shower; and it is a great pity that we should possess no title serving to distinguish this formation from its opposite, that of the more wide spread nimbus. You do not always see the process of development which I have described. We have showers and showers; showers which have been formed a long way off, and are carried by the winds over our heads before they have dispersed, and showers, too, which are so imbedded in other cloud forms that we fail to get a glimpse of their cirri-form summits, or even to distinguish the outline of their sides or base. Showers of thick small rain even fall, in some circumstances, from low clouds of the stratus type, but these clouds also, just before their precipitation commences, lose their definiteness of outline as regards their upper surface, always looking as if they were discharging rain or snow in an upward, as well as in a downward, direction. But the formation that I have described is decidedly that most distinctive of the local shower, in contrast to the wide-spread rain.

Now we all know that the first steps of the formation which I have described are often discernible without being followed by any shower at all. In fine weather, especially in the spring and summer, we often see cumulus forming day after day, attaining its greatest dimensions about the hour of highest temperature, and either dissolving altogether about sunset, or subsiding

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into the loose-spread stratus which is scattered at night-fall through the vapour plane. I must give you a few rough and ready rules which may be some assistance in judging of the probability or otherwise of passing showers.

First of all then, I would say, look to your barometer, and to the indications which it affords in connection with the quarter of the wind. Most of our showers are related to areas of depression existing over us or in our neighbourhood. We shall therefore rarely expect them when the barometer is very high, say much above 30 inches at sea level. Again, we have seen that passing showers are especially numerous on the right hand side and in the rear of a depression. Consequently, we shall be led to expect them when the wind is veering or seems likely to veer, and when the barometer is rising or seems likely to rise. Next you may study with some advantage the colours of the sky and of the landscape. These are, indeed, in many instances, more closely related to the advance or retreat of the extensive nimbus, for judging of the probabilities of which I have already given you what I consider more dependable rules. For example, a red dawn is commonly taken as a sign of bad weather, and the inference has of course a basis in fact. In the evening the minute particles of water, together with dust, suspended in the air, usually cause light, transmitted through a long stratum of this air, to be red. During the night a great number of these particles are deposited on the earth's surface. If after the precipitation in dew, the rays of the rising sun

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appear red, we conclude that the air still carries numerous water particles which, after the morning evaporation and the diurnal rise of the vapour plane, are likely to form rain-clouds. A grey or yellow sky in the evening is usually due to much cloud matter in the west, especially in the form of cirrus or cirro-stratus, stopping the direct rays of the sun, or a considerable portion of them.

"Visibility," or the remarkable distinctness of distant objects, is, on the other hand, another popular prognostic of rain. It is no doubt, to some extent, the effect of previous rains, the precipitation having washed the atmosphere of its dust, either in the district where the visibility is observed, or in that which lies to the windward of it. Unusual refraction is, I think, a more trustworthy sign, indicating that the rays which reach the eye have passed through closely contiguous strata of air of varying densities, the commingling of which is likely to produce precipitation. But these and other such like signs are inferior to those which we derive from a minute study of the cloud forms.

When cumulus begins to form under those other circumstances which lead us to suspect coming showers, watch its formation and appearance with great care. A very rapid upward development of the cloud, while the outline is hard and the base very level, is a bad sign; which is intensified if the protuberances of the upper surface are seen to toss and roll with much activity. When, as is very commonly the case, there are clouds of other species in the sky, notice these particularly. If there is a good deal of loose stratus, the remains of night-cloud,

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around the base of the cumuli, and the latter are forcing their domes far above these, and gradually absorbing or repelling them beneath, the occurrence of showers before nightfall is probable. On the other hand, if there is stratus at a moderate altitude, and cumuli are formed still lower down, and the summits of the latter seem inclined to spread out and blend with the stratus as they reach it, while the bases of the cumuli become ill-defined, and appear gradually melting, the weather is pretty sure to remain dry. In the latter case there is a sort of second cloud-plane in the middle region of the atmosphere, namely that occupied by the stratus, which serves both to impede the evaporation from the earth's surface by checking the solar rays, and also to conduct horizontally the electricities of the clouds, at a very early stage of their formation. On the left hand of the picture which you now see (Fig. 5), you have a likeness of one of these quiet and well-intentioned cumuli. The stratus in this particular instance is of a special kind, never, or hardly ever, seen before rain, which has received, I believe, the title of "rolled-cumulus," though I do not call it cumulus at all. On the right hand side of the picture I have given, by way of contrast, the bold level-based cumulus, which is often the precursor of a hail or thunder shower; a handsome, but rakish and suspicious character, whose proceedings you should watch with some care. By and by he will probably begin to assume his tufted crown, "fœnum habet in cornu"—to misquote a Latin poet—"hunc tu Romane caveto"—put on thy waterproof, O Briton.

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It is a very common thing, on those occasions when there is what I have called a second cloud-plane at no very great altitude, to see cumulus, when its summit reaches this plane, spreading out in very thick opaque folds, so that the cloud altogether may be in shape compared to a mushroom with a very thick stem. To the inexperienced eye these clouds have a somewhat stormy and formidable appearance, probably because they are rather similar in shape to those far loftier shower-clouds, whose summits have spread outwards into the cirrus regions of the atmosphere, and the untrained eye recognises form far more readily than distance. Yet clouds of the kind I am now speaking of rarely or never produce a shower. They may be seen at all times of the year, but especially in spring, particularly in the south-eastern parts of an anticyclone. They are most commonly accompanied with a good deal of haze, and associated with a dry and harsh atmosphere. One might almost suppose, from parts of his description, that these clouds are what Luke Howard intended to designate as cumulo-stratus; but other remarks which both he, Forster, and others make about the cumulo-stratus, show that they intended by this term to designate the cirrus-crowned cumulus, which I have spoken of to-night simply as the shower-cloud. There are other and later representations of cumulo-stratus, according to which this title ought to be given to ordinary cumulus co-existing in the sky with a good deal of stratus. As stated before, I am not attempting to reform the nomenclature of the clouds, being concerned

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with the things, and only incidentally with the names, and therefore shall not dwell upon this point further.

The mention, however, of cumulo-stratus leads me to ask your permission to introduce to you an especial favourite of my own, who comes with no credentials, and is, in fact, a sort of innominato. It is not simply a cumulus co-existing with stratus, but a true hybrid between cumulus and stratus, to which I only wish the name cumulo-stratus had been given. Of all the clouds that ever adorn our English skies there are few which I think more elegant, and there are none so distinctive of special, though rather uncommon, types of weather, as the one of which I am going to speak now. I have tried to picture for you, as you see (Fig. 6), some of these clouds, but I could not with exact fidelity represent either the uncontrolled irregularity of outline, or the exquisite delicacy of reflected lights which are manifested by these clouds when scattered over the sky. I may describe them, in general, as very high stratus, having numerous turrets or protuberances emanating from its upper surface. They would, by many, be denominated cirro-cumuli, but there is really nothing of the cirrus about them. From observations of the shadows thrown by these clouds, I have found their altitude to be rarely less than 14,000 feet. They therefore almost belong to that class which may be defined as upper current clouds. In direction of movement they are commonly intermediate between the cirrus-current and the surface-wind, but are much nearer to the former. The peculiarities of this type of cloud are as follow:—They

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hardly ever occur in our islands, except in summer, and rarely then, unless the temperature is above the mean. They are rather more prevalent in the inland districts than elsewhere, and they are, I believe, least common on the Atlantic coast, and especially uncommon on the west coast of Ireland. They are usually seen near the western and south-western limits of an anticyclone, when there happen to be one or more shallow depressions to the southward, that is over the Channel, France, or the Bay of Biscay. They seem to be associated with vast electrical disturbances in the higher regions of the atmosphere, and they are very commonly the precursors of our grandest thunderstorms. This is especially the case when they move with great velocity from a south-easterly or southerly point, while clouds a little below them are flying from N.E. or E. Under these circumstances, a single fragment of cloud of the type I am describing, however minute, occurring in a bright sky, and perhaps with a high and steady barometer, will sometimes enable the accurate observer to prognosticate thunder with a success which is astonishing to those unacquainted with his secret. These clouds sometimes disappear before the occurrence of a thunderstorm; the latter then takes place in the day time, and is formed from the cumulus type already described. But there is a remarkable class of thunderstorms which come on with the clouds of which we are now speaking. This cloud resembles ordinary stratus in one respect, that it glories in the night. Soon after sunset on a summer evening it often thickens and darkens in the S. and S.W., its under surface

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being disposed in numberless wave-like folds, through which, here and there, shine the highly reflecting sides of its broken but cumulus-like turrets. Presently the sheet lightning begins to illumine the southern sky, while a light easterly or northerly breeze is felt below. In a few hours the storm is raging in its might, a magnificent display of celestial fireworks, remarkably unproductive of any disastrous effects, and in this respect standing in marked contrast to the thunder-showers whose base is at a lower level, and which are first developed from clouds of the ordinary cumulus type. Those of our summer thunderstorms which occur during the night are, with very rare exceptions, of the sort which I have now described. You are not to suppose that the kind of clouds which I am speaking of undergo no change when passing into the form which produces the shower. Their behaviour is analogous to that of the ordinary shower-producing cumuli. Their summits run up so as to inosculate, in some cases, with cirrus at no great distance above them; in other cases those summits become spontaneously cirriform; and this change, probably accompanied by a neutralisation of electricities, is, so far as I have observed, and I have watched them through many a night, the essential requisite of their precipitation in rain.

You will observe that I have spoken principally in this Lecture of clouds as prognostics of rain rather than of fine weather. I may be forgiven for doing so in a climate in which, grumblers say, it is always safe to foretell rain; but in attempting to describe the rain-

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bringing clouds I have to some extent implied that the opposite types are, relatively speaking, signs of fine weather. But I must, before I conclude, say a few words on one type of cloud, the occurrence of which is especially a sign that no rain is immediately to be expected. The anticyclones, or areas of high barometer, are, as already mentioned, in a general way areas of fine and settled weather. In summer we commonly see within these areas almost cloudless skies. A little stratus occurs at night on some occasions, at an elevation of from 4,000 to 10,000 feet, and this is developed into cumulus of moderate dimensions during the day, while the unwashed atmosphere is usually slightly obscured by the haze produced from smoke and dust. At a great elevation cirrus may often be seen in comoid tufts, whose movement is extremely slow. In winter, on the other hand, neither cumulus nor cirrus is common near the central parts of an anticyclone; but the sky is rarely clear. A bed of nearly stationary stratus often covers the heavens for many days and nights in succession. This bed is frequently of vast extent, but of very small vertical thickness. Where gaps occur in it, such as that which I have tried to portray in the illustration which you now see (Fig. 7), we observe a sky totally devoid of every species of upper cloud. Now we infer, from facts which I cannot stay to describe to you now, that there is over every anticyclonic area a slight general downward movement of the atmosphere. In the summer the sun's rays dissolve the stratus, and the rapid evaporation taking place during the long and hot

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days sends up the local or scattered patches of cumulus or cirrus. In winter this does not take place. The vapour in the very high regions of the atmosphere is carried by the descending current towards the surface of the earth; it therefore probably experiences a rise of temperature, and, consequently, does not pass from the gaseous into the visible form. The surface of the earth is, however, losing heat by radiation, and at an altitude of about 3,000 feet or less (often much less) above that surface a temperature is encountered which is low enough to condense the gas into a level sheet of vapour. The remarkable continuity of this sheet I imagine to be due to the fact that wherever a break in it occurs the earth consequently loses more heat by radiation, as our thermometers in such circumstances abundantly show, and the sheet is consequently speedily reformed. You must not suppose that beneath this bed of stratus the atmosphere is always as clear as it is represented in this picture. It is so sometimes, but occasionally over a great expanse of country, and especially in the neighbourhood of our large towns, the atmosphere is obscured by thick fog; and the densest and darkest fogs which you experience in London are commonly those which occur beneath the "anticyclonic stratus" which I have been describing; these fogs being possibly due not only to the want of horizontal motion in the air, but partly also to the descending currents which accelerate the downward movement of the now water-laden particles of smoke.

It is remarkable that although strati-formed clouds are in general more characteristic of the sea than of the

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land, the stratus which I am speaking of is much more continuous over the land than over the sea. It is also noticeable that the breaking up of one of these banks of stratus is usually the first sign of a change from settled to unsettled weather. The explanation which I have attempted of the manner in which the stratus bank is formed, helps us to interpret both these facts. The relative warmth of the atmosphere over the sea in winter prevents the formation of the stratus. And, again, the cessation of the general descending current, or the commencement of ascending currents, necessarily attends the breaking up or the passing off of the anti-cyclone.

My subject has no limits, and you must be aware that I have selected to-night only a few, a very few, of the points of interest which it embraces. If I have taxed your patience you will, I hope, forgive me. If, in making my selection, I have served in any degree to direct your attention to, or to enliven your interest in, a marvellously neglected branch of study, I shall have done all that I could hope to do in an hour's lecture. In any case you will permit me to conclude with the expression of my hope that before some of us may lie the not impossible task of elaborating, by ceaseless and minute observation, the materials of a science of nephology yet unborn; and that to all of us may belong the opportunity of adding something to the enjoyment of life by a more watchful study of some of the least known, but most exquisitely delicate, of the operations of mighty Nature.

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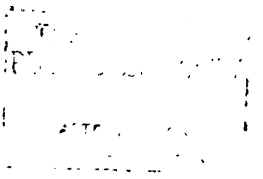

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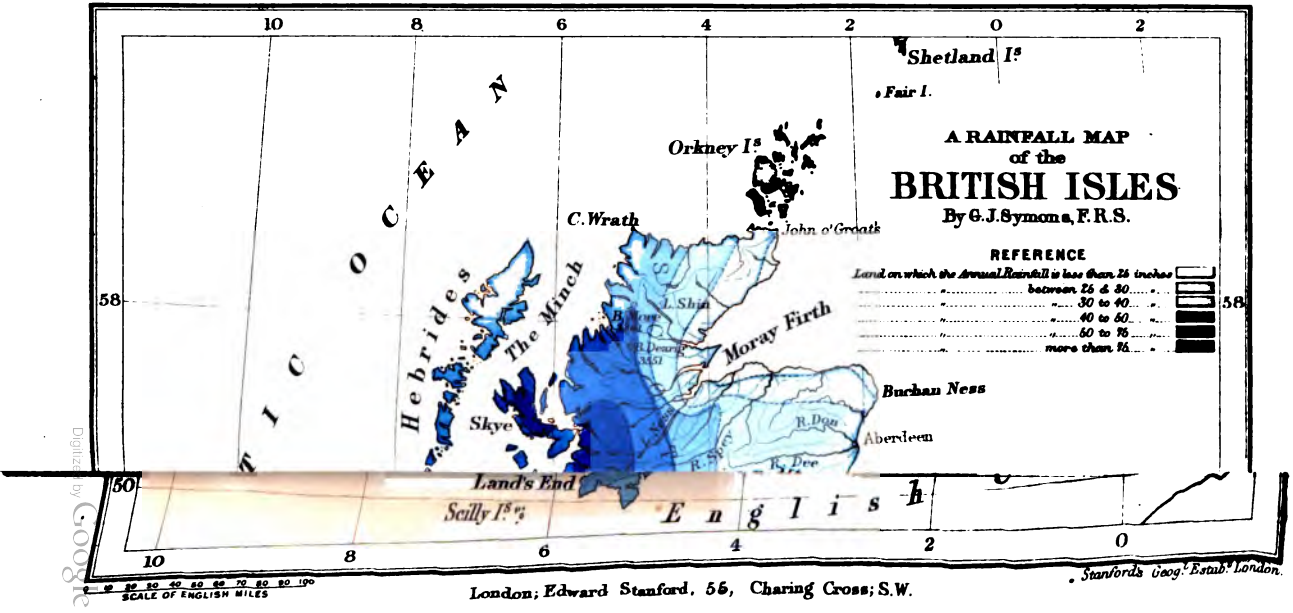

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LECTURE V.

N, SNOW, HAIL, AND ATMOSPHERIC ELECTRICITY.

Rain.

HAT IT IS.—We are very desirous that there ould not be any needless repetition in the present ourse of Lectures. Therefore, as my friend Dr. Mann lescribed somewhat fully the conditions under which water exists in the atmosphere, I am at liberty to dismiss the first three words in my syllabus very briefly, and I might do so in the four words—Rain is condensed vapour. But in case any one is now present who was unable to attend the first Lecture, I will amplify slightly. The atmosphere consists of oxygen, nitrogen, dust, and sundries, all which are classed as dry air, and also of a variable quantity of water in the state of vapour. The hotter the air the more vapour it can contain, and this capacity of the air for moisture increases at an increasing rate, so that if you mix together a cubic foot of saturated air at 92°, and another at 32°, they would have a mean temperature of 62°, but the vapour tenable at 92° is 15·7 grains, at 32° is 2·1, therefore our 2 cubic feet would contain 17·8 grains, or an average of 8·9, but at the temperature of the mixture the air can contain only 6·2 grains, therefore the excess of 2·7 grains must fall as rain.

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WHERE IT COMES FROM.—This question might also be answered as regards this country in three words—the West Indies; but further details are necessary. Some one, I think it was the late Commander Maury, likened the atmosphere to a steam-engine, whereof the tropical oceans were the boilers, and the temperate zones and the mountain-tops generally were the condensers. This is nearly true, the vertical sun raises large tracts of the ocean to the temperature of 80° and upwards, considerable evaporation ensues, and each cubic foot of the air in the tropics may be said to contain, roughly, 8 grains of vapour at the temperature of 76°; if that air be transported to these islands and reduced to their average temperature of 50°, it must part with nearly half its vapour, and would even then remain fully saturated. When one substitutes for grains and feet tons and miles, and reflects on the vast extent of the tropical oceans, there is no difficulty in understanding why winds from those regions deposit rain on all colder countries over which they blow.

WHY IT FALLS has almost necessarily been explained in the preceding section, but it may be well to point out that as the chief cause of rain is condensation by cold, and as hills are usually colder than the winds blowing against them, and likewise throw the air up to greater and colder altitudes, we naturally find the largest amount of rain in hilly districts exposed to currents of air coming direct from warmer oceans.

HOW IT IS MEASURED.—This is so simple a matter that it hardly seems expedient to occupy much time

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over it, but even with the simplest operation there is always a wrong way of doing it, and as there is nothing worse than bad observations, I shall go rather fully into the subject. We want to know how much rain falls, that is to say, how deep the water would stand upon the ground after a fall of rain, if none of it penetrated the soil or flowed off it. Suppose the floor of this room to be level, covered with concrete, and provided with a ledge all round to prevent the water running off, surely that would give an accurate measurement of the rainfall. No, it would not, because it would be very difficult to measure accurately the depth of the water, and because evaporation from so large a surface would soon diminish the quantity to be measured. Some form of funnel is therefore always employed.

DIFFERENT PATTERNS OF RAIN GAUGES.—I will not take you through the entire variety of patterns of gauge hitherto employed, probably nearly a hundred, but select two, each typical of many gauges now in use. First, on account of its extreme simplicity, I take the pattern of gauge used in very wet and mountainous districts. It is merely a double cylinder, the outer one for protection, the inner one to hold the rain; the inner cylinder is exactly the same size as the mouth of the gauge, therefore, if an inch of rain falls, the water in the inner cylinder will be 1 inch deep. A float rests on the water, and whenever it is desired to know how much rain has fallen, a rod, divided in inches and quarters, is dropped down until it rests on the float; the height which the rod is above the receiving surface

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shows the depth of rain fallen. I need not say that this is a rough plan, but it is accurate; the gauges generally agreeing with ordinary ones within 4 or 5 per cent. Secondly, I take a 5-inch Snowdon gauge, because it is the pattern of which the largest number are now at work. It will be seen that the water of any ordinary rainfall passes into the bottle, and all evaporation is prevented, as the only access to the external air is up the long pipe. If the rainfall exceeds the capacity of the bottle, or if the freezing of the water breaks the bottle, the record is not vitiated, because the water is retained in the cylinder, and can still be measured. The measurement is effected by pouring the water into a graduated glass, and as its area is perhaps only a tenth that of the funnel, it is evident that 1 inch of rain would fill such a glass 10 inches deep.

BEST SIZE, SHAPE, etc.—Experiments have shown that in ordinary circumstances it is not of any consequence what is the size of the receiving surface, nor does it make much difference whether the gauge be round or square, but circular gauges are certainly the better, because (1) it is easier to make a true circle than a true square; and (2) the influence of the rim (or the ratio of circumference to area) is less with a circle than with any other form.

Respecting the material for gauges, there is no doubt that copper is the best; but I may here address one word to manufacturers: many copper gauges are spoiled by being finished with edges rounded over iron wire; the iron rusts and the gauge becomes shabby;

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a fold of copper is sufficiently strong by itself, and the iron is merely a source of weakness. Tin coated with japan is cheaper than copper, and lasts about ten years, but copper lasts—well, longer than any observer.

MECHANICAL GAUGES.—By mechanical gauges I mean those wherein the water by its own weight sets trains of mechanism in motion, but as these are nearly all bad, and are rarely used, I will pass them without further comment.

STORM GAUGES.—It is in the highest degree important to know accurately the rate at which rain falls. But, for this purpose, the ordinary rain gauge is of little use; for, irrespective of the personal discomfort of standing in the rain in order to measure it at short intervals of time, the record would be vitiated by frequent interference with the rain gauge funnel. I have therefore designed two modes of avoiding the discomfort and the errors. The first plan was to place a small funnel on the top of a long and narrow glass tube, of such a size that 1 inch of rain would fill about 2 feet of tube; the tube was mounted on a black board, and a white float rising on the top of the water showed the fall of rain. An overflow pipe allowed the measurement to extend to 2 inches. This gauge was cheap, handy, and answered the two requirements of being read from indoors and not vitiating the true reading of the ordinary gauge. But it was awkward to empty, liable to be burst in frosty weather, not adapted for night observations, and trouble-

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simple, very accurate, and, as far as I know, faultless. The rain passes through the funnel down the pipe into a cylinder, wherein there is a float which rises as the water falls, and as it rises it turns the two hands; the longer (like the minute-hand of a clock) completes one revolution for 1 inch of rain, the shorter (like the hour hand) shows the number of inches, in this specimen 5 inches; but the number is simply dependent on the length of the cylinder, and by merely lengthening it the record could be extended to 10 or 20 inches if required for use where the rainfall is excessive.

ALTITUDE.—I must here also say a few words respecting the effect of the height above the surface of the ground at which a rain gauge is placed. Upwards of a century back it was known that rain gauges on lofty buildings collected much less than others near the ground. It seemed so strange that the nearer one went to the clouds the less was collected, that experiments were made in many places; the best known series was made in this immediate neighbourhood, in 1766, by Dr. Heberden, F.R.S., who had three similar gauges constructed, and placed, one in a garden near Westminster Abbey, one on the roof of a neighbouring house, and one on the centre tower of the Abbey; the result was, that in the garden near Westminster Abbey there fell 22·61 inches; on the roof of the house, 18·14 inches; on the square tower of the abbey, 12·10 inches. Similar experiments, and modifications of them, have been tried in many places, and almost always with similar results. The precise cause of the decrease was

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long vigorously disputed, and to this moment the complete explanation of the fact has not been given. I believe, however, that it is now acknowledged to be almost entirely due to wind, although I do not myself understand exactly in what way the wind produces this effect. Some years since, a series of gauges, of which the funnels were not horizontal but tilted at angles of $22\frac{1}{2}°$, 45°, $67\frac{1}{2}°$, and 90°, and kept face to the wind by vanes, was erected at the cost of Mr. Chrimes of Rotherham. On discussing the observations, I obtained results whence the preponderating influence of the wind's velocity seems indisputable. Recently, Mr. Dines has been making experiments of a similar character on the tower of his residence at Hersham, and these are shown, by the analysis given by Mr. Rogers Field in the *Meteorological Magazine*, to be in remarkable agreement with the wind's direction.

I ought, perhaps, to add that, as this diminution is sensible even down to the surface of the ground, it is indispensable that observers report accurately the height of the mouths of their gauges above the ground, and, for the sake of uniformity, that all new gauges be at 1 foot above the grass.

NECESSITY FOR INSPECTING RAIN GAUGE STATIONS.—Inspection always sounds like finding fault, and it must be admitted that such is its primary object, but, in my own case, I can truly say that it is much more agreeable when there is no fault to find. Measurement of rainfall is so easy and so simple, and the rules for observers are so ample, that there ought not to be

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much need for inspection. But there is; and it is to be regretted that, owing to the absence of adequate pecuniary resources, this inspection is not more extensively carried out than it is. The only consolation is that, firstly, grossly erroneous rain-gauges, and good gauges badly placed, are now much more rare than formerly; and secondly, stations are now so much more numerous that faulty records are less likely to escape detection. In the early days of inspection a few very gross cases were found, *e.g.* a rain gauge actually underneath a tree, another so close to a house that when the snow slipped off the thatch it fell on to the rain gauge, another with the edge of the gauge $\frac{1}{4}$ inch thick, instead of a knife edge; a measuring jar graduated in cubic inches, and used as being hundredths of an inch of rainfall; side tube gauges run empty at each observation. But, on the whole, the observations, both old and recent, come out remarkably well; a recent reduction of a group of about a dozen stations, in a tolerably level tract of country, showed only one discordant record, all the others agreeing within an inch.

COLLECTION OF RAINFALL STATISTICS.—It seems to me that it must always be unpleasant to speak of work done by oneself. If it has succeeded, the speaker appears to be praising himself, if it has failed, he can hardly like to say anything about it. Having had the guidance of the collection of the rainfall statistics of this country from the first large attempt, twenty years ago, up to the present time, I prefer, with your permission, to pass over that history, and deal merely with matters

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as they stand now. First, as to the observers, they are mostly amateurs, of whom the total number is nearly 2000, but besides them there are certain governmental, official, and semi-official stations, so that the total number of rain gauges, regularly observed in this country at the present time, is about 2200, say 1700 volunteer stations and 500 under one or other of the following bodies, viz. the Meteorological Council, the Meteorological Society, the Scottish Meteorological Society, the Board of Northern Lighthouses, Mr. Glaisher, and the Manchester, Sheffield, and Lincolnshire Railway. By a kindness which I fully appreciate, every one of these bodies sends me copies of its records, so that I am able to concentrate almost all (certainly 99 per cent of) the information obtained in the country. The advantage of such concentration is self-evident, and it is also partly reciprocal, for amid such a multitude of records it is far easier to detect errors than it would be to any one who receives only a few. The volunteer observers whom I have already mentioned, not only send up their returns regularly, but also contribute towards the unavoidably heavy expenses of checking, classifying, discussing, and publishing such a mass of statistics. Hence, and hence alone, it is that I am enabled to publish annually, at a comparatively low price, a general summary of all the rainfall observations made in the British Isles during the previous year. Nearly all the observations are made at 9 A.M. local

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as 9 A.M. sweeps across the British Isles from Lowestoft to the West of Ireland, no matter how wild the weather may be, forth go some 1500 or 2000 persons of all social ranks, from peer to peasant, to make their daily measurement of the amount of rain fallen. As to the position of these stations the best general idea is given by the map, but as it is a few years old, the present distribution is rather better than that shown by the map. With any large staff, changes by death and removal are unavoidable, and therefore constant vigilance is necessary to keep the whole country fully provided. At the present time observers are much needed between Thirsk and Whitby, and also in the S.S.W. of Ireland.

APPLICATIONS OF RAINFALL DATA TO PRACTICAL LIFE.—It is rather from plethora than from the reverse, that difficulty arises in this part of my Lecture. All the water in our rivers, lakes, and wells is stored rain; and so is, therefore, every drop of water that we use. Rainfall details are often wanted for very strange purposes: I will quote one as a specimen. A chemist invented a method of preventing the streets requiring to be watered as often as is usual; this he did by mixing with the water certain chemicals, which were calculated to abstract moisture from the air; he contracted with a certain parish, and was to be paid so much per quarter, less the cost of any watering which the authorities might think needful. This arrangement of course implied that if his method succeeded, no deduction should be made. Vested interests in the water carts, however, were so strong that a tremendous deduction was claimed;

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the inventor obtained details of the times at which the carts were sent out to water the roads, and then rainfall records showing that the watering carts were sent out while it was raining!

DRAINAGE.—With the exception of one Irish engineer, I never heard any one maintain that drainage could be perfectly carried out without any knowledge of the fall of rain. The reverse is of course the truth, for in towns one must know what is the maximum storm rain to be dealt with, just as for bridges one must know the maximum flood which the bridge must be able to carry off. There are, however, wider, more scientific, and very valuable objects, which accurate rainfall data, supported by improved hydraulic arrangements, have effected in almost every country in Europe, except England, where we have such a reverence for vested interests that if a man has been injuring his neighbours for fifty years he has to be paid for ceasing to do so. It would probably be within the truth to say that the Hydrological commissions of Lyons and of the Seine have saved to France tens of thousands of pounds, and it would be equally true to say that the English Government has allowed the Thames to do damage to an equal amount.

FLOOD WARNING.—I have almost anticipated this subject in referring to Lyons and Paris, where there is a system of flood warnings in full operation. In both cases a system of rain-gauge stations has been organised at the head of the watersheds; daily reports are sent to the central office, and so great is the experience

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gained by constant practice, that no flood ever reaches either city until long after its advent has been announced, and usually the height predicted is realised within a few inches. I do not for a moment say that Thames floods could either be prevented or precisely predicted, but as our great rain-storms usually travel but slowly from west to east, and as the somewhat porous nature of most of England allows the rain to percolate, there is plenty of time to make arrangements which would mitigate evils which at present exist.

WATERWORKS.—Excepting London (whereof the inhabitants seem too fond of Thames water to desire any with a purer history), it may probably be said with truth that half the urban population of the United Kingdom is supplied by gravitation waterworks, *i.e.* by the collection and storage of the rainfall on upland districts. This is another point of contact between rainfall researches and practical life, for accurate knowledge of the amount of rainfall is indispensable for the proper designing of such works, and of determining the amount of compensation water to be sent down the streams for the use of the millowners upon them.

SALMON CATCHING.—This is a subject which does not, at first sight, seem very intimately connected with rainfall, but investigations by Mr. Horsfall, carried back into the eighteenth century, appear to prove a distinct connection between the rainfall of one year and the weight of salmon sent to market in the following year.

SUGAR-MAKING.—One of the most elaborate investigations of rainfall data ever undertaken was made

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under the supervision of Sir Rawson Rawson while he was Governor of Barbadoes. A copy of his very valuable report is in the library of the Society, and therefore I need only say that Sir Rawson Rawson proves not only a distinct connection between the fall of rain and the total sugar produce of the island, but also that it is possible beforehand to predict within narrow limits what the total yield of the season will be.

EFFECT OF ALTITUDE ON RAINFALL.—I now leave the applications of rainfall data, and come to some of the leading results hitherto obtained. It will perhaps be remembered that at the beginning of this Lecture I said that cold hill-tops acted as condensers. I am not sure that their action in producing rain is *wholly* by virtue of their temperature, but, leaving debateable ground, we come to the undeniable fact that in ordinary circumstances there is a gradual increase in the fall of rain proportional to the altitude of the locality above the level of the sea. Roughly stated, the rainfall increases 3 or 4 per cent on its sea-level value for each 100 feet of altitude above the sea. For instance, if the rainfall of the lowest part of London be 24 inches, then for the highest part of Hampstead (400 feet) we should have about 27 inches. This rule, though generally near the truth, is sometimes terribly wrong, especially in mountain districts. It is evident that it must be limited in its application by the fact that, as the rain comes from the clouds, as soon as the altitude becomes equal to that of the clouds the increase must cease, and so we find it, for the gauges on the top of Scaw-

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fell, Great End, Helvellyn, etc., collect *less* than those in the valleys near them, the gauges on these mountain-tops being often above the clouds. Irregularity is also produced by the different conditions which prevail on two sides of a hill, the rate of increase up the S.W. slope being different from that up the N.E., and both depending on the altitude of the summit; accurate determinations of these rates are much required.

DETAILS OF MEAN FALL IN BRITISH ISLES AND AT SOME FOREIGN STATIONS.—It would never do to crowd a lecture with a mass of figures, and yet figures are the end and aim of all rainfall work. I must therefore try to point out the broad features, keeping the details out of sight as much as possible. First, then, people have long spoken of mean rainfall, but the term was used for very inaccurate results. They took the arithmetical average of any number of yearly values they could get hold of, from 3 to 20, and without paying the slightest attention to whether they were ordinary years, or very wet ones, or very dry ones; they forthwith announced that arithmetical average as the mean rainfall of that place. The error of this mode of working is greater the shorter the period (unless it be one specially selected), and vanishes if the period embraces 20 years or upwards. In constructing a table of mean rainfall there are two evils between which it seems necessary to choose. The longer the period of observation the more trustworthy is the mean deduced from it, but if one is only to work up long registers there will be large tracts of country without any. If one works

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with short registers the means are liable to be in error through exceptional seasons not being adequately neutralised. I have adopted two ways of surmounting these difficulties. One is by taking first only the long registers, determining their true means, and the ratio which the fall in each year bears to the mean of the long period. Then, by applying these ratios to the observations which were made for only a few years, one obtains a very close approach to the true mean for those stations. Another plan is to take several long registers and to hunt through them for a short group of years of which the average is nearly the same as the average of a long period. The years 1860-65 form such a group, and the map is based upon a calculation of the mean fall during those six years at all the stations whence I could obtain records. It is tinted gradually deeper and deeper for each increase of 5 inches of mean annual rainfall. When it was prepared that map represented, as accurately as the time at my disposal allowed, the rainfall distribution over the country, but the number of stations has been so greatly increased of late years that I hope shortly to produce a far more accurate one. The general features will doubtless remain much the same, the alterations being, I expect, chiefly due to the insertion of local details. The map is so self explanatory that I need not say much about it. The tints are deepest where the total fall is greatest, but no attempt is made separately to denote extremely wet stations, all those at which upwards of 75

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localities at which this amount is exceeded are both few and small; the largest is on the west of Scotland, but the one where the amounts are greatest is the English Lake District, where several stations have an annual rainfall of 100 inches; one, Seathwaite in Borrowdale, at the south end of Derwentwater, has an average of 140 inches; and a little above it, on the slope of the hill, near Stye Head, the mean fall is 175 inches, or about 15 feet, and in wet years it is considerably more than 200 inches or 17 feet.

FOREIGN RAIN.—It would take an entire evening to treat properly of the rainfall of the globe, and there is also another reason why I should not attempt it, namely, that for large tracts of land we have no records, and for other parts their accuracy is doubtful. I must not dwell longer upon it than to say that while there are parts of the earth's surface where the fall of rain is so rare that they are called *rainless*, there are others where the fall is twenty-four times as great as in London. Both extremes are to be met with in India, or upon its borders, for instance at Kurrachee, in the N.W. of India, where the mean annual fall is only 7 inches, and it is less still further to the N.W.; on the contrary, on the Khasia Hills, N.E. of Calcutta, the average is generally said to be 610 inches (or 51 feet), but I have not seen any recent returns from that station.

I must not, however, leave you with the impression that no progress is being made towards an accurate survey of the rainfall of the world, but the work is so

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gigantic that at present we have only fragmentary monographs. I may mention briefly some of the best; for Europe the *Regenkarte*, by Dr. Otto Krümmel; for India the map compiled I believe originally for Dr. Brandis, and reprinted annually in the blue book *East India* (*Progress and Condition*); for the United States in the Smithsonian tables by Schott; and for Africa in the very original and interesting article by Keith Johnston in Stanford's recent book upon that country. Copies of all these maps are on the table. Thanks largely to the energy of Mr. Todd of Adelaide, we shall soon be able to know much of the rainfall even of central Australia.

SEASONAL DISTRIBUTION.—This feature of rainfall distribution is very marked in some tropical regions, as, for instance, at Bombay, where 67 inches fall in the four months June to September, 2 inches in October, making 69 inches in five months, and only 1¼ inch in the 7 months between October one year and June of the next. At other stations rain occurs almost daily throughout the year. In the United Kingdom the fall is nearly equally distributed throughout the year. At dry stations October is usually the wettest month, except at stations where heavy thunder-storm rains have occurred repeatedly in July or August; April is generally the driest month. At wet stations the proximity of mountains has a curiously marked effect upon the curve of monthly rainfall, as it so largely increases the fall in the winter months as to make December or January the wettest month of the year.

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This is a feature not yet generally recognised by hydraulic engineers, but of great importance, for summer rains are so reduced by evaporation that it is the winter rains which are of the greatest utility, and their disproportionate excess in mountain districts adds enormously to the yield of those districts.

DAILY FALL AND STORM RAINS.—It will not be possible to separate these two items of the syllabus, and therefore I mention them together. Daily falls of small amount do not call for special notice; daily falls of large amount are generally due to storms. In the British Isles the greatest amount on one day in each year, at all the stations, is about $1\frac{1}{2}$ inch, but no year passes without far heavier falls at individual stations, at one or more of which upwards of 4 inches always fall (hence follows the rule, that all rain gauges must hold at least that amount). The extreme amount which can be deposited in twenty-four hours in the British Isles is not known; it is a question of catching and measuring a broken waterspout. Measurement of the water flowing off Black Hambledon, near Todmorden, on July 9, 1870, indicated, according to the local surveyor, Mr. Greenwood, a rainfall of at least 9 inches, and when the disastrous rain of August 6, 1857, occurred at Scarborough, the only rain gauge in the town, one which held $9\frac{1}{2}$ inches, was found to be full and overflowing.

These British amounts sink into insignificance beside those produced by the monsoon rains in India; such as, for example, 15·31 inches on June 27, 1869, at Bombay, and 25·49 on July 1, 1851, at Cherrapoonjee.

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SECULAR VARIATION.—I do not like this term. I need not say that it has no reference to things temporal as distinguished from others, neither does it refer, as some dictionaries make it, merely to events occurring once in a century. One cannot say periodicity, because that implies the recurrence of identical phenomena at periodic times, whereas all that I desire to convey is the idea of changes which are traced through long periods of years.

In the *Report of the British Association* for 1866 I gave the full details of calculations whereby I obtained the approximate rainfall of each year from 1726 to 1865, and though it gave no clue to the law of sequence of wet and dry years, it did bring out one rather alarming fact. For waterworks' purposes engineers often calculate upon the yield of three consecutive dry years, and consider that the average of three such years will be $\frac{1}{6}$th less than the mean of a long period, *i.e.* that it will be about 83 per cent of the truth. In the middle of the eighteenth century there was a period of thirteen consecutive years, from 1738 to 1750 both inclusive, with an average rainfall of only 71 per cent; even if we assume these observations to be 10 per cent in error, we still have thirteen consecutive years with only 78 per cent, instead of three years with 83 per cent. Such a drought as that would, under the altered circumstances of the present day, produce inconvenience and suffering of a very important character. I see no reason why it should not recur, and I certainly know of no one who has taken the possibility into consideration.

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Snow.

WHAT IT IS.—Snow is ice. Yes, the gentle snow-flake which will fall and rest upon a spider's web without breaking it is the same material as will support the weight of thousands of persons, and vehicles of almost any weight. It is not easy to the untrained mind to realise that snow is a hard substance, its remarkable lightness, whiteness, and softness being wholly due to its extremely delicate structure. Snow is frozen vapour, and if in its fall it neither passes through strata of air above the temperature of melting ice, nor meets that temperature upon the earth's surface, it falls in figures of such extreme beauty that no words of mine could adequately describe their elegance. I therefore take a few from the masterly pen of John Tyndall.

Professor Tyndall describes a fall of snow he witnessed on the summit of Monte Rosa, as "a shower of frozen flowers; all of them were six-leaved; some of the leaves threw out lateral ribs like ferns; some were rounded, others arrowy and serrated; some were close, others reticulated, but there was no deviation from the six-leaved type. Nature seemed determined to make us some compensation for the loss of all prospect, and thus showered down upon us those lovely blossoms of the frost, and had a spirit of the mountain inquired my choice—the view, or the frozen flowers—I should have hesitated before giving up that exquisite vegetation. It was wonderful to think of, as well as beautiful to behold. Let us imagine the eye gifted with a micro-

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scopic power sufficient to enable it to see the molecules which composed those starry crystals; to observe the solid nucleus formed and floating in the air; to see it drawing towards it its allied atoms, and these arranging themselves as if they moved to music, and ended by rendering that music concrete. Surely such an exhibition of power, such an apparent demonstration of a resident intelligence in what we are accustomed to call 'brute matter,' would appear perfectly miraculous, and yet the reality would, if we could see it, transcend the fancy. If the Houses of Parliament were built up by the forces resident in their own bricks and lithologic blocks, and without the aid of hodman or mason, there would be nothing intrinsically more wonderful in the process than in the molecular architecture which delighted us upon the summit of Monte Rosa."

Even in the temperate climate of London in about one snowfall out of five it will be found that the snow, instead of being, as most people regard it, a mere irregularly agglomerated mass of light ice, is really crystallised in exquisitely beautiful forms. The crystals are rarely less than $\frac{1}{10}$th of an inch across, and therefore their general form is easily visible without a lens. Six-rayed snow is said by Kepler to have been mentioned by Socrates, but I have not been able to find the quotation. The earliest reference to these figures which I have yet found is in the work by Olaus Magnus, *Historia de Gentibus Septentrionalibus*, published at Rome in 1555, wherein the author says: "In one day and night you shall see fifteen or twenty distinct forms

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of snow," but he gives no engravings. The earliest that I have seen are in a very rare tract, written in 1660 by Thomas Bartholinus, *De Figurâ Nivis.* I must not allow myself to drift into the bibliography of snow crystals, but may just mention that among those who have written upon the subject are, besides those already mentioned, such great names as those of Descartes and Cassini. The finest early collection of engravings (upwards of 400) are in a work, *De Sneeuw Figuuren,* published at Haerlem, in 1747, by Dr. Engelman. Lastly, we come to by far the largest and finest set, finest both artistically and scientifically, because they are the most beautiful and the most accurate. I mean those observed by Mr. Glaisher, and engraved in the fifth Annual Report of this Society. I cannot pretend to represent them in all their graceful beauty, and have not selected the prettiest, but those which are so common that they are to be found in nearly all the sets of engravings; though the finer details are only given in Mr. Glaisher's paper.

One word as to the best mode of observing these crystals. The first caution to be given is, do not breathe towards them; all the finer details would be instantly melted, and you would either see heavy patterns, or, more probably, none at all. Roughly, and without apparatus of any kind, many beautiful crystals may be seen lying on previously fallen snow; it affords a bed both cold and soft, and they will lie on it unchanged for hours. For accurate work, slips of coloured glass, set at various angles, and allowed to become quite cold,

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afford excellent receiving surfaces, and a strong lens or very low-power microscope can then be used. Provided the figure be symmetrical, it is only necessary to draw the details on one radius, the other five can be added subsequently.

MEASURING SNOW.—Snow sometimes puzzles rain observers, as it is not so easily measured as rain. Very simple rules have been drawn up, and therefore I will not enter upon the subject. *Very roughly*, 1 foot of snow may be taken as equal to 1 inch of rain.

Hail.

WHAT IT IS.—When one can find in existence a paragraph which exactly suits one's purpose, I think it is better to quote it and acknowledge the origin, than to twist it round and pass it off as original. I do not know how to commence this section better than with a paragraph from Mr. Glaisher's translation of Flammarion's *L'Atmosphère*. "Hail occurs during a thunderstorm when the temperature is very high upon the surface of the ground, but decreases rapidly with elevation. This rapid decrease is the principal element in the formation of hail, and it has been known to be as much as 1° in a little more than 100 feet. What then takes place in the region of the clouds? Those above, from 10 to 20 or 25 thousand feet high, contain, the highest of them, ice at about −30° Fahrenheit, the lowest of them vesicular water at about zero Fahrenheit. The lower clouds contain vesicular water above 32°. As a rule, these clouds travel in different directions, and hail is formed when

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there is a collision and admixture of winds, currents, and clouds, the temperatures of which are different. The vapour which then resolves itself into rain freezes instantaneously in so low a temperature." It will be observed that in this paragraph no part in the formation is ascribed to electricity. It is obvious that such mixtures of air-currents as those above mentioned must produce great electrical disturbances, and many theories invoking electricity as the cause of the formation of hail, have been put forward. It is proverbially difficult to separate cause and effect, but as the causes above stated seem to be sufficient, I prefer to leave the electrical phenomena in the class of effects.

SOME OF ITS FORMS.—Hailstones in this country are usually the size of peas, and approximately spherical, but these are the ordinary and unimportant stones. Scarcely a year passes without the fall of very different stones. A black cloud is seen in the south, a roaring sound (like a wave retreating over a pebble beach) is heard, and in five minutes the standing crops are thrashed, thousands of panes of glass are broken, the ground is covered with from 2 to 6 inches of ice, and a blaze of sunshine illuminates a scene of desolation. The hailstones in this country are not often more than 2 inches across, but even these hit very hard. I remember seeing in the suburbs of London a pony, which two days previously had been exposed to a hail-storm, and whose back was covered with lumps arising from the blows he had received. In the hail-storm which passed over Stronsay in the Orkneys in 1818, it

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is stated that "not only were nearly all the geese and smaller fowl killed, but the terrified black cattle and horses, which had broken their tethers, and been observed at the beginning of the fall of hail running violently backward and forward, galloping and flinging, had now collected together in a herd. Mr. Caithness at length made his way to them through the half-melted ice; they still trembled exceedingly; some of the horses had lain flat down on the grass, with their heads stretched out, and all of the animals were more or less cut and bleeding. Some of the weaker horses, the farmer says, will never recover; the milch cows, he adds, were 'struck yeld,' or gave no more milk, and, indeed, would not suffer the people to attempt to milk them any more."

I am afraid to say anything respecting extremely large hailstones, for you will scarcely believe me. I did hope to put before you to-night a piece of corrugated iron roofing, perforated by a recent hail-storm in India, but I have mislaid the address of the gentleman who has brought it over, and therefore that very indisputable evidence is not forthcoming.

The shape and density of hailstones vary greatly; they usually show more or less of a radial structure, and are often formed of concentric shells of alternately clear and opaque ice. A very fine collection of engravings is given in Abich's paper, *Uber Krystallinischen Hagel im Thrialethischen Gebirge*, published at Tiflis in the Caucasus.

NOISE BEFORE IT FALLS.—This I have already

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mentioned; it is doubtless due chiefly to the stones striking each other, and partly to their striking buildings etc., in their line of approach.

RARITY AT NIGHT.—This is well known, but I have never seen it explained, although it seems to me that if hail at night were not a rarity, it would be impossible to accept the explanation of its formation which I have already given. Hail is rare at night because the air is *not* then usually "very hot near the surface of the ground," nor does the temperature then "decrease rapidly with elevation." The conditions requisite for the formation of hail rarely exist, and hail is equally rare.

Atmospheric Electricity.

Both from want of time and from want of ability, I am unable to treat this subject properly. Had other circumstances permitted, an evening would have been devoted to it, and then, it is needless to add, the Lecture would have been given by some Fellow less incompetent than myself. But rain, hail, and thunderstorms go together, and therefore, *nolens volens*, it appears in my syllabus. It used to be the fashion to ascribe to the action of electricity all unexplained phenomena; a wiser course is now adopted, and people are not too conceited to own that they do not know everything.

I shall not attempt to give a connected statement respecting atmospheric electricity, but merely some scraps of information which may perhaps induce others to devote themselves to the subject.

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Years ago, when Francis Ronalds was director of Kew Observatory, the upper portion of that building was fitted up with such a collection of electrometers as had never been established before, and has never been equalled since. Respecting the results obtained, I would refer you to the Reports of the Kew Committee, to Kaemtz, and to Drew.

At the Royal Observatory, Greenwich, attempts have been made for many years to observe atmospheric electricity, but they have been very unsuccessful, the insulation of the exploring wire having rarely been perfect for long together.

The most elaborate experiments with exploring wires were those made on the Quantock Hills, in Somersetshire, by Andrew Crosse. Much intensely interesting information is given in the "Memorials" published by his widow. I may mention one statement, viz. that frequently storm clouds appeared zonal, that is, alternate portions positively and negatively electrified.

For general and very rough purposes an ordinary gold-leaf electrometer gives useful indications, but it is far inferior to even the cheapest form of Sir William Thomson's electrometer, which is certainly the instrument of the present, and possibly of the future also.

People often speak of summer sheet lightning as harmless—so it is *to them.* I early learned that it was by no means always as harmless as it looks, and my experience may fix the fact in your memory. Many years ago, one lovely summer evening, I saw from London beautiful lightning playing along the S.W. and W.

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horizon: I watched it for an hour, and enjoyed the sight. Two days afterwards tidings arrived of a fearful thunder and hail storm at a village some 30 miles from London, and that in a row of cottages belonging to me not one pane of glass on the south side was left whole.

Lightning is visible at great distances, I believe as far as 150 miles; thunder is stated to be audible for only about 10 miles, but Mr. Corder in the October number of the *Natural History Journal* says, under date September 8th, "Counting the seconds between the flash and the thunder I got twice up to 130 seconds, or 27 miles distant. This is the farthest I ever counted. Flammarion gives 10 miles as the maximum distance at which thunder is audible; but I have heard it several times at about 100 seconds, or 21 miles."

The frequency of English thunderstorms increases with the temperature, but it is also greater with hot damp weather than with hot dry weather.

Summer thunderstorms are supposed to be more destructive than those of other periods, but the larger percentage of accidents may be due to more people being in the fields, and stupidly sheltering under trees, in summer.

LIGHTNING CONDUCTORS.—I cannot understand why English people have hitherto been so slow to erect lightning conductors, nor why, when they do put them up, they are made so stunted that they look as if ashamed to show themselves. A properly fitted and cared-for conductor gives absolute protection to the building on which it is erected, and if, as the saying is, "A penny-

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worth of ease is worth a penny," it is strange indeed why some people allow their nervous system to be deranged instead of so protecting their houses that they may be able to watch with calmness and with pleasure one of nature's grandest sights.

Although the general principles which govern the erection of lightning conductors are well known, there are some minor points which require discussion. I am glad to end these disconnected remarks by informing you that delegates from the Physical Society, the Society of Telegraph Engineers, and the Royal Institute of British Architects, have accepted an invitation from the Council of this Society, and are endeavouring to settle all doubtful points. I must not mention names, but the delegates are nearly all men of cosmopolitan renown.

One remark in conclusion.—The leading idea which it was my wish to urge upon you seems constantly to have escaped mention. Perhaps, however, it is well that it has been so, for last words are sometimes longest remembered. I desire to impress upon you my firm conviction that the great need of rainfall work, as of every other branch of meteorology, is neither more observations nor more money (though neither of these is to be despised), but more brains, more hard workers, more deep thinkers.

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LECTURE VI.

THE NATURE, METHODS, AND GENERAL OBJECTS OF METEOROLOGY.

METEOROLOGY is the science of the atmosphere, of *τὰ μετέωρα*, the things above the earth, as Aristotle has it, and its interest to every one hardly needs remark. Inasmuch as in the air "we live and move and have our being," any knowledge which we can gain from time to time of its condition, and of the changes which are taking place in it, cannot fail to be of importance to our material welfare, our health, and our comfort.

Almost every one imagines himself a born meteorologist, at least in so far as every one is perfectly ready to volunteer an opinion on the prospects of the day's weather, and from the earliest ages men have been watching the sky and the changes in its covering, and recording their experiences. Who that has read Greek does not know the humour with which the meteorological theories of the Athenian weather-prophets are ridiculed by Aristophanes in *The Clouds?* Nevertheless, though men have studied meteorology more or less systematically since the time of Aristotle, who wrote the first treatise on the subject, but little progress was made in the science until the invention of the barometer and

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thermometer some 200 years ago. And we must admit that even yet it has hardly made good its title to a place among the exact sciences.

The reason of this is easily explained—*Firstly*, we live at the bottom of the atmospheric ocean, and of this the upper layers are all but utterly inaccessible to us, so that what half-knowledge we can gain of their condition is mostly derived from conjecture. We know really nothing of any phenomenon occurring above the level of the stratum which we inhabit. *Secondly*, the observations we make of the physical state of the air are affected to such a degree by local accidents, such as the elevation, contour, and slope of the ground, nay, even by the very character of the soil, that we meet with material variations of meteorological circumstances even within the limits of a single county. In this respect meteorology offers a strong contrast to astronomy, the recognised queen of all the exact sciences. The objects of observation and study which are pursued by astronomers are at such a distance from our planet, that it is practically of little importance whether the observer be placed at Greenwich, at Rome, or at Washington. The phenomena themselves are identical, and other things being equal, the difficulties of effecting the observation depend mainly on the meteorological conditions of the locality. In fact, in the absence of clouds, the range of phenomena within the ken of an astronomer is limited only by the horizon of his station and the power of his telescope.

But in meteorology the case is widely different. The phenomena are not the same at two different points

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of observation. The temperature of the air and the motion of the wind in the street outside differ appreciably from what is being experienced in the middle of Hyde Park, and *à fortiori* from what is felt outside the city, as at Kew or Greenwich.

Hence we see the necessity of covering the country with a network of independent meteorological stations for climatological purposes, as the observer at each place cannot do more than record the phenomena exhibited by the actual particles of the atmosphere which come in contact with his instruments. In fact, we may exemplify the difference between the two sciences by an illustration taken from biology. The astronomer may be compared to one of the more highly organised among the mollusca, such as the octopus or the argonaut, which is endowed with powers of motion, and can seek its food afield, while the meteorologist is, like a mussel or an oyster, anchored to one spot, and obliged to make the best of such nutriment as may chance to be swept within his reach.

If we seek to investigate the climate of a thinly peopled region, like one of our Australian colonies, we are thankful if we secure stations even 250 miles apart, but when we come to the consideration of our own climate at home, we find that a distance of 50 miles is still too great to ensure that no special peculiarities shall escape our notice, and expose us to the charge of unduly depreciating, or of not being keenly alive to, the climatic advantages of each rising watering-place.

In all this multiplication of stations we must not

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hold that *quantity* will in any way replace *quality*. The results from one bad station in a district will often throw doubt on the figures of most conscientious observers.

In more than one instance of recent times, it has come out that results obtained by laborious calculation have been proved to be almost worthless, owing to the disregard in former times of obvious precautions to ensure accuracy in the observations and their registration.

This is sufficient to show that it is not enough to buy good instruments, and set them up with due regard to exposure, etc., unless you can provide an accurate and punctual observer, and ensure that, when this person chances to be absent, a thoroughly competent substitute shall be ready to take his or her place. I say *her* advisedly, for ladies, thanks to their patience, are some of the best observers we can have.

The duty of observing regularly is not an easy task. In this busy country observers would object to observe three times a day, and yet that is a *sine quâ non* in most other systems. We here only ask for readings at 9 A.M. and 9 P.M., and yet our observers find the latter hour very irksome.

Meteorology, like all other sciences, demands self-denial from her votaries, and there are but few men who would be willing, if their life was spared so long, to record steadily in one district for more than half a century, like my friend Dr. Charles Clouston, of Sandwick Manse in the Orkneys.

There are but few recognised observatories of which

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the registers, of uniformly high character, go back for fifty years. The accurate records at each spot simply correspond with the period of office at the place of individual observers. When each died or left the place, the chain was broken.

In recent inquiries into rainfall periodicity, the tables cited have been from widely different localities, and when my friend Mr. Dines published, some years ago, his tables of the rainfall of London, he could not find, even for our National Observatory at Greenwich, a record of so simple a nature as that of rain kept with its present accuracy, before 1815.

If, then, we find difficulty in securing accurate information for the climate of our highly civilised Europe, what are we to say about our knowledge of the climates of the other continents. This is scanty enough, if we look for data of high scientific value. On a recent occasion our secretary, Mr. Symons, published a valuable summary of the existing statistics of the climates of our colonies, but full as were the details in that paper, it showed us how much we have still to learn, before we can pretend to have gained a really comprehensive insight into the meteorological conditions of the globe.

The earliest systematic effort to obtain this information was the scheme organised in this country by the Committee of Physics and Meteorology of the Royal Society in 1840, and managed by Sir E. Sabine. A similar system was conducted in Russia under Kupffer. The original *raison d'être* of this system was the confirmation of the Gaussian theory of Terrestrial Magnet-

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ism, but Meteorology was also embraced within its scope. The results obtained at these colonial observatories have, in the few instances in which they have been discussed, thrown a flood of light on the condition of the atmosphere in widely different parts of the globe. It is a great pity that this system has not been continued. Of the four of our colonial observatories only two, Cape Town and Toronto, survive. The Russians, however, have at all events maintained their stations, which continue to furnish valuable information from the distant regions of Siberia.

We are therefore compelled to admit that any accurate knowledge we possess of the meteorology of the globe is in great measure derived from observations taken over a comparatively limited portion of the northern hemisphere. In all this talk about the demand for new stations, I must not be supposed to deny that, on numerous questions of great importance, abundance of material exists for any one who wishes to discuss it. The most pressing want of meteorology at present is, as Mr. Symons justly says, not observations, but brains to utilise them.

The stations which I have hitherto mentioned have been all on land, but as the sea takes up two-thirds of the earth's surface, we must not disregard it as an area for the collection of information. This is easy enough to say, but when we reflect a moment, we see that the problem is one of extreme complexity. To illustrate my meaning by a familiar illustration, I would say that the endeavour to give a correct account of

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the climate, etc., of any district of the sea, presents much the same prospects of success as we should have, were we set to determine the climate of the different parts of France, from observations made by English tourists in their railway journeys through the length and breadth of the land. Ships at sea can never rest unless becalmed or hove-to, and so the observations made at noon to-day may be taken at a spot 300 miles distant from the ship's position yesterday or to-morrow. Hence we see the comparative fruitlessness of the attempts to deduce means of any value from the log of a single ship, no two successive observations having been made under *exactly* the same circumstances, except when she was at anchor.

What we have to do is to take a definite area, say a one-degree square, in any part of the sea, and deal with all the ships which pass through it. Supposing that these ships have similar instruments and equally qualified observers, we are met at once by this difficulty:—Suppose that this square really had seven days of easterly wind in each of two months, and that only one ship passed through it in each of the months. A, bound to the eastward, would probably record twenty observations of the east wind, as she would be beating against it and detained in the square, while B, bound westwards, would fly through the square, and probably only put down the east wind twice. What is the true record of the wind for either month?

C again may have been becalmed in the square for three days in an anticyclone, with his barometer rang-

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ing above 30·5 inches, while D, on another occasion may have been hove-to in a winter gale, with his barometer below 29 inches.

In every one of these cases the local conditions will affect the observations taken, and any means obtained from their discussion. How are we possibly to lay hold of the sound web of truth which lies under this motley tangle of conflicting information? The problem is a tough one to solve, but we think that we have partially solved it for some small areas.

The complication is even worse than I have described when we wish to deal with the climate of the sea at large, for we find that information cannot be got from certain unfrequented parts of the sea, unless ships are sent on purpose to get it, and this is a result not easy of attainment.

We see that in dealing with ocean meteorology it is nearly hopeless to look for a complete representation of the geographical distribution of meteorological conditions, and that no matter how carefully we collect and discuss our information, a large part of the isobars and isotherms which have been drawn over the sea are mere approximations. Still, when we look at the great amount of meteorological knowledge which has been deduced from the logs of our marine observers, we take courage and feel that although it may be long before *absolute* truth is obtained, we are yet bringing out valuable approximations for the use of the navigator, as well as for the physical geographer.

I have hitherto dealt with the subject of observing

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stations solely in relation to climatology and the physics of the atmosphere. There is, however, another direction in which it may be prosecuted, and of which the importance cannot be over-estimated—that is the study of weather. We may almost say that this is a new science, rendered possible by the facilities of communication afforded by the electric telegraph.

This branch of inquiry demands heavy expenditure, and a great amount of discipline and organisation, so that it cannot be prosecuted by individual observers, or at isolated stations, no matter how perfectly they may be equipped and managed. In his latest report General Myer congratulates his Government on possessing in the observing staff of the Chief Signal Office, a body of drilled men available for the suppression of any riot or disturbance. The idea of our thirty telegraphic reporters forming a volunteer corps is rather amusing.

This line of inquiry—weather telegraphy—in no way falls within the scope of objects followed by our Society. I need not therefore detain you by describing its methods; I would, however, point out one broad feature of distinction between climatology and weather study as regards the collection of observations. In the former case, as you have just heard, we seek above all for continuous records from the same spot. In the latter, geographical position and freedom from conditions which will affect the character of the observations, especially of wind, are of paramount importance. If an opportunity occurs of obtaining a report from a new station which will give us earlier and surer intimation

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of coming changes of weather, we reject ruthlessly offers of observations from the most ably served observatory in the district.

As regards synoptic work on a large scale, the importance of which to the meteorology of the future is being daily more and more acknowledged, it is evident that the records of the oldest established station are of no higher value than those of a ship on her rapid passage over the ocean.

Here we come to a point of view from which we may look our critics in the face and boldly ask for more, no matter how our shelves may be bending beneath the weight of undiscussed records. When we do ask for more, however, it is not from these islands or from the more civilised countries, but from the "unsurveyed world" of Africa, Central Asia, Australia, South America, and our own north-west American territories. I need hardly say that meteorological processes go on whether men be present to register them or not, and, could we get it, a knowledge of what is going on at present over at least the whole northern hemisphere would be necessary for the complete elucidation of the agencies which produce our weather.

We do not want more synoptic stations in these islands, for we have far too many already. Upwards of sixty observers have sent in their names to join in the Washington Scheme, and there is not room for six wind arrows for the British kingdom on any charts which are likely to be published to show the sequences

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moment one good station on Spitzbergen or Jan Mayen would be worth as much as ten in Western Europe.

Here I may be allowed a short digression to say that, in the cause of science, it must be a matter of regret that the far-seeing scheme, which has lately been revived by Count Wilczek and Lieutenant Weyprecht, of girdling the North Pole with a belt of observing stations, does not exhibit many symptoms of vitality. The plan is not sensational enough to attract extensive public notice, and there is too much ground for fear that it will never come to a worthy realisation.

I have hitherto been speaking mainly of the collection of meteorological observations, and must now briefly touch upon the methods of the science. I must reluctantly admit that these are not by any means satisfactorily settled as yet. While some meteorologists complain of an unnecessary and inquisitive interference with the time-honoured habits of practised observers, and decry all attempts of International Congresses to introduce uniformity of procedure and publication, others come forward to demand the excommunication of every observer who does not conform to recognised rules, *by which they mean the regulations enforced in their own special organisation.* The cry of these gentlemen is for uniformity in instruments, methods, and hours, and they tacitly assume that no one has a right to a voice in the matter who does not accept their dicta. The fact is, that on all the points which I have noticed, great differences of opinion and practice exist. As to instruments, the Russians call for siphon tubes, while

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we prefer Fortin's or Kew pattern barometers. For thermometric exposure the battle of the screens is raging with its full fury. The Italians hold to their north-side exposure, the "Fenestra Meteorologica." The Norwegians, in great measure the Germans, and the Dutch, do the same. The Russians, and we ourselves, have free-standing screens designed to cut off all radiation; and lastly the French, at least at several stations, place the thermometers among trees or shrubs, with a simple board to keep off the direct rays of the sun.

How can we look for minute accuracy in results with such wide differences of procedure? the idea is simply absurd!

In hygrometry too, what tale does Mr. Dines tell, in the latest part of our *Journal*, of the differences in the determination of the dew point by his own apparatus and by the ordinary methods? Again, who will maintain that the wet-bulb gives any satisfactory indications in time of frost? Are we on this account to go back to the half-forgotten hair hygrometer of Saussure?

These statements are sufficient to show that, as regards *methods*, we are still in want of suggestions from experienced physicists; as regards hours of observation, what are we to say? At the first meteorological conference, thirty-three years ago, at the Cambridge Meeting of the British Association in 1845, the meteorologists present agreed to differ on this knotty point, and the way out of that difficulty which was pro-

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struments. We have had these instruments for many years, but at the present day we are no nearer uniformity than our fathers were a generation ago.

We must only, therefore, submit to the inevitable, and make the best of what we can get. It is certain that the broad principles of our science have been laid down by men who did not look for such refinement in observation as is now demanded.

I may perhaps be permitted to return over the ground trodden by my predecessors during the last five weeks, and give you a very brief account of some of these broad principles, which have already been ascertained with tolerable certainty, but which we are all endeavouring to establish on a firmer basis.

Firstly, as regards temperature, Mr. Laughton placed before you a large map showing the respective curves of yearly summer and winter temperature. The idea of drawing these curves we owe to A. von Humboldt; the labour of carrying out the suggestion and making the subject his own, has been the lifelong work of Dove. As the general outcome of his researches on this head he proposed the charts which I exhibit, the abnormals of the globe. They were published by the British Association in 1853, and I have selected those for January and July. The general principle of these charts is, that if we conceive of the earth as a homogeneous sphere with temperature decreasing uniformly from the equator to either pole, each parallel of latitude should have a definite temperature.

The charts show you how widely the facts differ

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from this ideal state of things. I need only point out how strongly they bring out the contrasting influences on climate of continent and ocean. The greatest positive anomaly in January, or to speak in plain English, the most unnatural warmth in winter is that of the North Atlantic, due to the Gulf Stream ; and the shores of what the Americans call "Walrussia" are also much favoured, thanks to the Kuro Siwo of the Japanese seas. On the other hand, the two cold poles are shown in Arctic Asia and America.

In July the Asiatic cold area is transferred to the Aleutian Islands, chilled by the efflux of cold water through Behrings' Straits, while the Northern Seas generally exhibit a defect of temperature, owing, as Mr. Laughton explained, to the high specific heat of water, which absorbs all the caloric it can get to lay it up against not a rainy, but a cold day.

In the southern hemisphere we see in their winter the chill which falls along the coast of Peru, while the comparatively high latitude of the Australian colonies enables that continent to produce on its east coast a defect of as much as 10°.

Those of you who have read Lyell's *Principles of Geology* will remember how, by shuffling the continents and oceans, like a pack of cards, he illustrated the possibility of the former existence on the earth of periods at which the tropical warmth of our cretaceous sea, and the piercing cold of the glacial epoch had respectively prevailed.

It is, however, hopeless to attempt to deal with

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temperature at greater length at present, and I shall now proceed to describe the rain chart which was merely touched upon by Mr. Symons.

In it we notice how the sea-winds are in most cases the rain carriers to the coasts. The wettest regions in the globe are within or close to the tropics, where, at Gorgonia, near Panama, Dampier declared that the rain fell faster than he could drink it; and where, at Cherrapoonjee, in the Khasia hills, not less than 600 inches fell within six months. The falls on the western Ghauts do not come far short of this. When we look to our own shores we find at Stye Head and Sprinkling Tarn (which well deserves its name) an amount almost comparable with the deluges which visit tropical stations in the rainy season.

The rainfall of a district is, however, mainly influenced by its proximity to the western coasts of its country, and by the lie of the mountain ranges by which it is traversed or encircled.

A chart like that I show does not tell one hundredth part of what we have to learn about rain. Had we monthly charts, we could show on them the seasonal peculiarities and the relations of the rain to the prevalent winds. Such a chart as we have is, however, a prodigious advance on those which were in use twenty years ago, on which the rain was shown in belts decreasing from 100 inches in the torrid zone to 15 or less in the frigid.

I shall, however, pass on with the remark that the question of the rainfall and the degree to which it may

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be modified by human agency, is one which is now being considered by many European Governments. Now that it is found that rivers, such as the Danube, the Rhine, and the Volga, are silting up their beds, and that navigation for scores of miles has been stopped by shoals, while at the same time the residents on the banks of the lower waters have been yearly more and more exposed to the ravages of floods, the governments have begun to intervene, as it appears that the only rivers which exhibit these effects are those whose banks and drainage basins have been recklessly despoiled of their forests. The authorities then step in and say that severe measures are required to ensure that the mischief shall not increase till it defies check.

In more than one of our own colonies an ignorance of the principles on which, under ordinary circumstances, the rainfall of a district depends, has led to the excessive clearing of woodland and brush, whether it be for the "chena" rice cultivation of Ceylon, or the sugar plantations of Mauritius, and as a result in either case the utter subversion of the natural hydraulic system of the country.

Time would fail me were I to attempt to describe to you the state of our knowledge of the distribution of barometrical pressure and of wind, which it is the great merit of Mr. Buchan to have established on a satisfactory basis. I must therefore pass on to say a few words about one of the questions of physical meteorology, as contrasted with climatology.

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you that temperature has a daily range, for when the sky is not obscured by fog the weather is at least warmer towards 2 P.M. than it is about sunrise. It may, however, surprise those who have not lived in tropical climates to learn that the barometer has a daily range showing maxima at about 9 A.M. and 9 P.M., and minima at about 3 A.M. and P.M., and that in the torrid zone, if this be interrupted, there must be some serious disturbance of the atmosphere brewing. In our latitudes the changes produced by storms, or, as they are called in scientific language, the non-periodic variations, are so large that they mask these minor oscillations, which are usually traceable only in very calm weather.

The fact of this diurnal range being known, we have to search for its cause, and this is cosmical, as it affects the entire atmosphere. No satisfactory explanation of it has yet been given, but our late president Mr. Eaton, and Mr. Buchan, appear to have entered independently on a line of inquiry which bids fair to be fruitful in results.

You see from the diagram that there is a decided difference between the curves for Kew and Barnaoul, types respectively of insular and continental climates.

Mr. Eaton has calculated these curves from seven British observatories, and he shows how the continental character gradually imprints itself on the course of the curves as we travel from the Atlantic seaboard towards the most continental station, Kew. He shows that this difference is related to the diurnal range of temperature. Where this is small, as at Valencia, we have the morn-

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ing minimum more marked than that in the afternoon, while at Kew the reverse is the case. The other observatories show a gradual progression, in time and appearance, from one type to the other.

Mr. Buchan has taken up the same inquiry on a more extensive scale, but with less rigorous demand for accuracy in the materials used, and he shows how the curve of diurnal range is affected in time and shape by proximity to the sea, and even to the great lakes of North America.

This points out to us that the vapour present in the air is a factor which is not to be disregarded, and yet, as I have told you, our knowledge of this element is most unsatisfactory.

A friend of mine, a most careful investigator, undertook, years ago, the discussion of barometrical diurnal range for all stations over the globe which could show honest, two-hourly observations, even for a few years. The labour of the calculation is complete, but he finds himself at a loss for information as to all the other elements, and no explanation of the phenomenon is possible without ample materials.

Here, again, we ask for more, and for such inquiries as this we want the most refined instruments and the most scrupulous regard to accuracy of registration. Not only do we want the observations from stations on the ground, to speak in common parlance, but we long to sound the aerial ocean, by placing our instruments on mountain peaks, and, would it were possible! in balloons. We know that the curves of diurnal range, on Pike's

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Peak (14,000 ft.) and at Mount Washington and the Puy de Dôme (each 6000 ft.) differ materially from those formed on the plains below.

Here is a noble field for future meteorologists to undertake, to devise some means of gaining intelligence of what is passing in the atmosphere, above our heads. Without such observations our knowledge of meteorological processes cannot fail to be more or less incomplete and unsatisfying.

We now come to the concluding toast of the evening—our noble selves—the utility of meteorology, or of the Meteorological Society, to the general public. When jotting down the syllabus of this Lecture which is in your hands, I said that meteorology demanded a knowledge of other sciences, but it would have been more appropriate to say that the student of these sciences would be the better for meteorological knowledge. It is hardly needful to urge this point further when we reflect what use our president has made of his meteorological acquirements in his long career. What engineer is there on the roll of the Institution of Civil Engineers who does not anxiously seek information from us on questions of water-supply, of tidal pressure on sea walls, or of wind force on Cleopatra's needle?

We may then ask ourselves, What are the ultimate uses of meteorology? and the answer to this is, They are twofold.

Firstly, there is the strictly scientific use, the enabling us to gain a more intimate knowledge of the conditions

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of our own atmosphere, and thereby of the earth as a member of the solar system.

Secondly, however, its immediate practical use is the foretelling of weather. Shirk the admission how we may, it cannot be denied that the most abstruse discussions of meteorological data have hardly another object than the determination of the average conditions of the climate of each place, and of the amount of variability which may be anticipated in the march of each element. What is this but forecasting?

In marine meteorology, again, we search laboriously for true mean values to indicate to the seaman where he may find "a fair wind and a favourable current," and what is this but implied prophecy?

The fact is, there is not a profession, not a handicraft, not a process in animal or vegetable life, which is not influenced by meteorological changes, and there is not a human being to whom a knowledge of coming weather would not be of value.

Had we, a quarter of a century ago, known the rigour of the Crimean climate, who would have dared to have sent out an army unprepared to meet the hardships of a Black Sea winter? Ask the physician at what price he would value the power of giving timely warning of the coming of a "cold snap" to his patients. Ask the builders of London what they have lost in the last ten years by sudden frosts or unexpected downpours of rain. Above all things, go to the farmer and ask what he would freely pay to know at seed-time what weather he might really expect in harvest.

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The roll is endless,—a knowledge of meteorology is of the very first importance in every stage of human life, civilised or uncivilised.

Hence we learn the attractiveness of all the manifold attempts made to foretell the character of the weather and seasons, whether these be the venturesome storm warnings of our Transatlantic neighbours, or the sun-spot researches of Mr. Meldrum and Dr. Hunter.

With reference to all such inquiries, my friend Captain Hoffmeyer has furnished me with an apt remark, "When the proper time arrives, a Kepler will be surely forthcoming to discover the laws by which our science works; for us to endeavour to force the plant in its growth is hopeless."

When we look at the prospects of meteorology, I think we need not despair. What though Pascal and Herschel have passed away with many lesser artificers of the goodly structure of our science; while Dove and Sabine, though still among us, have long ceased to work! Yet, if we look around and see men like Hann, Mohn, Wojeikoff, and though last not least, our own Buchan, we may challenge any one to say that the gifts of patient investigation and of far-seeing generalisation are not still present in our midst.

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